TAXONOMIC CLASSIFICATION OF HUMUS FORMS IN ECOSYSTEMS OF BRITISH COLUMBIA

FIRST APPROXIMATION

Land Management Report NUMBER 8

AUGUST 1981

Province of British Columbia
Ministry of

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Taxonomic Classification of Humus Forms in Ecosystems of British Columbia

First Approximation

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1981

Province of British Columbia
Ministry of Forests

LEGISLATIVE
VICTORIA,

Canadian Cataloguing in Publication Data
Main entry under title:
Taxonomic classification of humus forms in ecosystems of British Columbia

(Land management report, ISSN 0702-9861; no. 8)

"First approximation"
Bibliography: p.
ISBN 0-7719-8659-9

1. Humus - British Columbia. 2. Forest soils - British Columbia. I. Klinka, K., 1937-
II. British Columbia. Ministry of Forests. III. Series.

S592.8.T38 631.4'17'09711 C81-902262-2

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Published by the
Information Services Branch
Ministry of Forests
Province of British Columbia
Victoria, B.C.
V8W 3E7

Abstract

A hierarchical system for the classification of humus forms is proposed. The proposed system has been developed because of difficulties encountered with previous systems in discriminating between humus forms, and in relating them to ecosystems. It is based on earlier systems, but takes advantage of extensive recent field experience obtained from the Ecological Classification Programme in British Columbia.

The classification and methodology for description are based on morphological properties of humus forms. Keys to the taxa and descriptions of representative humus form profiles are presented and are intended as practical aids to ordering knowledge, stimulating research and improving interpretations about humus forms and ecosystems. The classification is considered to be a first approximation and is open to refinement upon testing and further studies.

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Acknowledgements

Appreciation is expressed to those who offered guidance, assistance and support in preparing this first approximation. Valuable general or specific comments were received from T.M. Ballard, Department of Soil Science, University of British Columbia; C. Tarnocai, Land Resource Research Institute, Department of Agriculture; T. Vold, Resource Analysis Branch, Ministry of Environment; and the Ecological Program Staff, Ministry of Forests, including J. Pojar (Prince Rupert Forest Region), F.C. Nuszdorfer (Vancouver Forest Region), W.J. Watt and C.A.S. Smith (Cariboo Forest Region), D. Lloyd and W. Erickson (Kamloops Forest Region), S.M. Hope and A.J. McLeod (Prince George Forest Region) and G.A. Utzig (Nelson Forest Region).

Acknowledgements for assistance and co-operation are due to the members of the Working Group on Organic Horizons, Folisols, and Humus Form Classification; to R.M. Laird, Ministry of Forests, for helping in preparing the final manuscript; to R. Carter and R.E. Carter for editing; to L. Skoda, Canadian Cartographics Ltd., and P. Frank, Ministry of Forests, for the preparation of the figures; to K. Valentine, Agriculture Canada, for photomicrography; and to L. Leclerc and K.L. Villalobos, Ministry of Forests, for the typing and preparation of the manuscript.

Introduction

Background

Bernier's (1968) descriptive outline of forest humus form classification, adopted by the Canadian Soil Survey Committee (Dumanski (ed.) 1978), has been used until recently by the British Columbia Ministry of Forests, in classifying humus forms. Because humus forms can be applied as differentiating or accessory characteristics for various taxa in the system of ecosystem classification used by the British Columbia Ministry of Forests, this classification system has greatly enhanced their ecological studies. However, during its decade of use, weaknesses have been exposed concerning definitions of organic horizons, methods of describing humus forms, terminology, treatment of non-conforming materials, the definition of moder humus forms, the tentative classification status of humus forms associated with semi-terrestrial and grassland ecosystems, and inconsistencies in the hierarchical structure.

A review of existing classifications of humus forms used in the U.S.A. (Hoover and Lunt 1952, Wilde 1971) and in Europe (Hartmann 1952, Kubiena 1953, Duchaufour 1960) indicated that they could not advantageously replace Bernier's system because they embodied similar weaknesses. In particular, the terms used to describe and classify humus forms were found to be inconsistent: expressions being used internationally were found to have two or more meanings, and the same entities were known under several names. Doubts have been expressed as to whether these names are really synonymous (Bernier 1968, Howard 1969, Wilde 1971). Another difficulty is that even when the names of those humus forms recognized by Kubiena (1953) or others are employed, they are not applied uniformly. The same is true of the horizon designation: the terms are not used uniformly nor do authors clearly state how they are using the terms (Babel 1975).

So, because of the weaknesses in the existing system and those used elsewhere, the Ecological Programme Staff[1] suggested that a revision of Bernier's classification system be initiated.

Approach

Ideally, a taxonomic classification of humus forms should ultimately be based on the physical, chemical and biological properties of humus forms which correlate readily with identifiable morphological properties. However, because of present inadequacies in the existing data base, purely morphological properties had to be used. This approach underlies most of the existing humus form classifications (Romell and Heiberg 1931, Heiberg and Chandler 1941, Mader 1953, Kubiena 1953, Barratt 1964, Wilde 1966 and 1971, Bernier 1968). In particular, Romell and Heiberg (1931), Wilde (1966 and 1971) and Babel (1975) have emphasized the importance of the readily determinable morphological features of humus forms (such as horizons, their thickness, colour, fabric, non-conforming materials and biota) for classification purposes. In addition to a detailed morphological description, some physical and chemical properties have been determined. A meaningful set of chemical analyses for humus materials is still the subject of research. In addition, how the morphological properties correlate with quantitative properties remains to be tested, and precise definitions of class boundaries for horizons and taxa still need to be determined by laboratory analyses.

The nomenclature employed for classes (taxa) at the highest level of generalization is based on three internationally recognized terms: mor, moder and mull. Names for taxa of lower level categories are formed by prefixing modifiers, formed mostly from Greek or Latin roots. These modifiers suggest some of the more important properties and, where possible, the taxonomic differentiae for a particular class. Such a system has been used consistently by Wilde (1966, 1971) for humus forms and by Soil Survey Staff (1975) in soil taxonomy.

Importance of the Taxonomy

Within the constraints imposed by both environmental and management objectives, the general goal of forestry management is to utilize and maintain the productivity of the ecosystems under management and, when possible, to increase productivity. Because of the important relationships between the properties of humus forms and forest productivity, meeting this goal requires knowledge regarding humus forms and, in addition, a classification system which will permit the application of that knowledge to similar humus forms in areas which have not been studied in detail. The taxonomic classification, in other words, provides an important tool which can be used for developing interpretations for forest management. The keys to the taxa and the descriptions of representative humus form profiles can be used as practical aids in ordering knowledge and for improving interpretations about humus forms and ecosystems.

Since 1975, the Ministry of Forests has been directing attention to the systematic development of a common scientific base for site (ecosystem) - specific management of the forest resource (Schmidt 1978). The taxonomic classification system which is presented here is expected to contribute to that goal.

Synopsis

In the first part of this report, the taxonomic classification of humus forms is presented. The methods used to describe humus forms and the methods of sampling and analysis are presented in Appendices I and II. The classification has been tested to a limited degree to substantiate the significance of the differentiated units, and the results have been encouraging. They are presented in the latter part of this report.

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[1] In the context of this study, the Ecological Programme Staff is a group of pedologists and ecologists responsible for an ecological classification programme carried out by the British Columbia Ministry of Forests.

Humus Form, Horizons and Related Terms

Humus

Humus, in a broad sense, refers to the complex organic products of the decomposition of plant or animal debris. These materials are more stable than their precursors, and are generally dark in colour, colloidal, and commonly associated with mineral constituents in soil. In soils in general, and particularly in organic material accumulating above the mineral soil surface, humus is closely associated with varying proportions of undecomposed or semi-decomposed organic materials, which cannot properly be termed humus. While "humus" is a valuable conceptual term, in practical studies it is often difficult (if not impossible) to achieve a physical separation of humus from other organic soil constituents. The term "humic substances" is often applied to organic fractions isolated from soil in the laboratory, and which are dominated by materials with humus-like properties, but which may also include substances which do not meet the strict definition of humus. Humic substances include such operationally defined fractions as humic acid, fulvic acid and humin.

The formation of humus is termed 'humification', and subsequent modification of humus, involving oxidative or other changes in chemical structure, can be referred to as "maturation" of the humus or its fractions.

"Forest floor" and "duff"[1] are terms used by many forest scientists and practitioners in North America to designate humus forms and a kind of humus form, respectively. In this context, "forest floor" refers to organic materials that have formed at and near the mineral soil surface and can include both humus and unhumified material. "Duff", in addition to a reference to forest floor in general, has also been used as a formative element in naming the taxa of Mull humus forms, and is synonymous with Mor in the systems of Romell and Heiberg (1931), Heiberg and Chandler (1941) and Hoover and Lunt (1952). The terms duff and forest floor are not used in the proposed classification. The term "forest humus" has been used in the same sense as "forest floor" or its constituent layers, but will be used here only to describe true humus (see above) present in, or formed under a forest ecosystem.

The continual interaction of all processes involved in humus and soil formation leads to the differentiation of more or less distinct horizontal layers, termed horizons, which collectively constitute the pedon. Both organic and mineral horizons are recognized when describing a pedon. For the most part, organic horizons of mineral soils or, in the upper solum of organic soils can be designated as humus horizons, only if substantial transformation of original compounds to humus has taken place.

[1]Duff - the intermediate layer, or the more or less decomposed organic matter, just below the litter (Waksman 1938).

Duff mull - a type of forest humus transitional between mull and mor (Glossary of Soil Science Terms, SSSA 1970).

Humus Form[2]

The humus form, introduced by Müller (1878), is defined as a group of soil horizons located at or near the surface of a pedon, which have formed from organic residues, either separate from, or intermixed with mineral materials. Thus a humus form may be comprised of entirely organic, or both mineral and organic horizons. The mineral horizons which are included in humus forms are restricted to melanized A horizons characterized by a significant accumulation of organic matter from residues of root systems or the activity of soil fauna, both which may be associated with infiltration. Although organic matter may be found in B and C horizons, these are not considered components of the humus form (Babel 1975, Barratt 1964). Humus forms are considered natural bodies, like the soil with which they are associated. In relation to the rest of the pedon, they are characterized by the most intensive biological activity.

Humus Form Profile

The sequence of organic and mineral horizons in a humus form constitutes the humus form profile. This profile and its morphological and chemical properties are used in the classification of humus forms.

It has been suggested that a definition of the smallest three-dimensional unit which can be considered a humus form is needed in order to provide a uniform taxonomic basis. However, it is questionable whether its lateral dimensions should coincide with those for the pedon. Several workers characterizing humus forms in British Columbia, Washington and Oregon noted their inherent variability and indicated that the sequence and thickness of horizons in humus forms of forest ecosystems can change very abruptly. Thus, using a smaller lateral dimension than 1 m for the humus form is appropriate. A study investigating morphological variability of humus forms is in progress, but provisionally, a lateral dimension of 0.5 m is proposed. The vertical dimension is to the depth of the control section.

Control Section

The organic and mineral horizons that form at and near the surface of a pedon (Soil Survey Staff 1975, CSSC

[2]Hartmann (1952) and other workers applied in humus studies the terms humus form and humus type. The definition of humus form given by Hartmann agrees with that rendered above. The term "humus type" refers to the kind of humus formation; i.e. to physical, chemical and/or biological processes controlling or influencing the formation of humus forms in a given ecosystematic setting. Hartmann recognized the zoogenous, fungal (mainly *Eumycetes* including *Ascomycetes, Phycomycetes* and *Basidiomycetes*), anaerobic, abiologic and aquatic types of humus formation. Evidently, a relationship exists between taxa at higher levels of our proposed classification and the humus types, as defined by Hartmann. This follows from the selection of differentiae for the taxa: the properties that reflect the environment or resulting from processes of humus formation.

1978) constitute the control section of humus forms. All organic horizons, but not all mineral horizons of the control section make up a humus form profile.

1. In organic soils, the control section extends from the surface[1] to a depth of 40 cm (e.g. it approximates the depth at the surface tier used in the classification of organic soils). If a lithic, paralithic or permafrost contact, or fragmental materials occur at a depth shallower than 40 cm, the control section extends from the surface to the contact (Fig. 1a). In these cases, the control section is identical to the humus form profile.

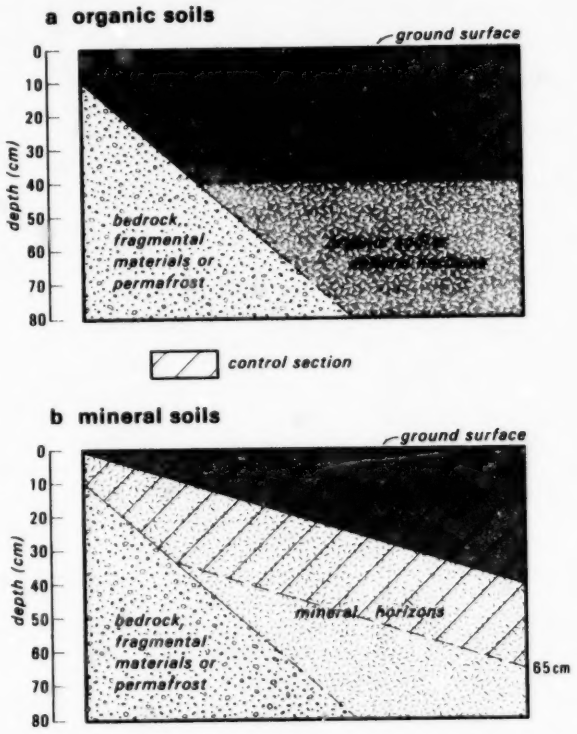

Figure 1. Control section of humus forms in organic (a) and mineral soils (b).

2. In mineral soils, the control section extends from the surface to a depth of 25 cm beneath the boundary between organic and mineral horizons. If a lithic, paralithic or permafrost contact, or fragmental materials occur at a depth less than 25 cm from the organic/mineral horizon interface, the control section extends from the surface to the contact (Fig. 1b). In these cases, the humus form profile corresponds with the entire control section, only if the mineral horizons within the latter are enriched by organic matter, as previously defined.

In the latter case the concept of the epipedon (Soil Survey Staff 1975) was adopted and the proposed 25 cm thickness is over the minimum depth requirement used for most of the defined epipedons. The control section as defined above is adequate to characterize humus formation in mineral soils.

Horizons

The classification of humus forms is based on the descriptions of organic and mineral horizons in a humus form profile. A soil horizon has been defined as a layer of organic or mineral soil material approximately parallel to the ground surface with characteristics produced by soil forming processes (Soil Survey Staff 1975, CSSC 1978). The horizons in the humus form profile manifest the genesis and properties of humus forms and also influence those of the whole soil. Since the definitions of taxa are based on the kinds, sequence, and properties of horizons, the precise definitions and designations of the horizons in the humus form profile are essential to classification.

Designations for Horizons

Capital letters are used for master horizons. They include L, F, H, O and A (horizons), indicating dominant kinds of organic materials degree of composition, or enrichment of organic matter.

In addition to the master horizons, the S layer (Forsslund 1945) is adopted. This layer is one containing a dense mat of living bryophytes (e.g. *Sphagnum*) in the humus form control section. However, it is not used for classification.

Lowercase letters are used as suffixes to indicate variations in the range of properties of master horizons.

If a horizon designated by these symbols is further subdivided vertically, the subdivisions are indicated by placing an arabic number after a lowercase suffix. If no lowercase suffix is suitable to indicate a specific attribute of a horizon, an arabic number is placed after the capital letter (e.g. F1) and the reason for the subdivision is explained in the horizon description. Transitional horizons, whose parts cannot be conveniently separated, are designated by a combination of capital letter symbols (e.g. FH).

There is a need to improve conventions governing the use of symbols to indicate variations within master organic horizons. When compared to mineral horizons, the absence of provision for more specific characterization is striking. Therefore, the consistent use of lowercase suffixes for all organic master horizons is recommended. Definitions for the subdivisions follow.

Definitions of Master Horizons

Four master organic horizons are recognized: L, F, H, and O; the master mineral horizon is A. An organic horizon contains more than 17% organic carbon (approximately 30% organic matter) by weight in the mineral soil fraction finer than 2 mm.

[1] The soil surface is interpreted here as the surface of the first soil horizon. Although in most cases the soil surface is identical to the ground surface, in some ecosystems the ground surface may be continuously or discontinuously covered by materials which are not considered to be a part of a soil horizon, either due to their nature (e.g. a layer of live *Sphagnum* mosses) or location in relation to the ground surface (e.g. partly detached or suspended organic residues).

The CSSC (1978) recognizes two groups of master organic horizons: the L, F, and H, and O horizons. The L, F, and H horizons are terrestrial (upland) master organic horizons of most mineral soils and the Folisol (Folists)[1] great group of the Organic order. The O horizon is a semi-terrestrial (wetland) master organic horizon of the Fibrisol (Fibrists), Mesisol (Hemists) and Humisol (Saprists) great groups of the Organic order. It may also overlie mineral horizons of the Gleysolic order ("aqu" suborders that have an aquic moisture regime) and gleyed subgroups of other orders. These groups have been separated according to origin of minerals and soil moisture regime[2]. It is difficult at times to designate an organic horizon in one or the other of these two groups given present definitions and criteria. Furthermore, L, F, and H, and O master organic horizons may develop in a common humus form profile. Although not stated in the CSSC (1978), pedologists usually use a combination of several criteria to judge if the organic horizon belongs to either of these two groups. These criteria are presented in Table 1.

The following definitions were proposed to the Expert Committee on Soil Survey by Trowbridge (1980).

L - (litter, förna): a terrestrial master organic horizon consisting of relatively fresh organic residues in which virtually entire original structures are discernible. May be discoloured and show some signs of biotic activity but is not substantially comminuted and does not show macroscopically obvious signs of decomposition.

The organic materials of the L horizons appear as recently fallen foliage, twigs, wood and other detached organic materials and form a layer approximately parallel to the ground surface. Thus, in pedons that have an L horizon, the ground surface coincides with the soil surface. These materials are essentially unaltered, but, occasionally, they may be discoloured and leached of most of the soluble constituents. Abiological disintegration and chemical alteration (Babel 1975) may be very slight. Rooting is absent in the L horizons. The L horizons correspond in part to the O1 horizon (Soil Survey Staff 1975).

TABLE 1. *Guidelines for the Differentiation of Organic Master Horizons (after Trowbridge 1980)*

Criteria	L, F and H horizons [Terrestrial (upland) ecosystems]	O horizons [Semi-terrestrial (wetland) ecosystems]
Physiography	Generally sloping to level	Generally depressional
Soil moisture regime	Very xeric to (hygric)[1]	(hygric) to subhydric to (hydric)
Drainage class of the underlying mineral soil	Rapid to imperfect (can be poor to very poor)	Poor to very poor
Water table	Absent in horizons (may fluctuate in response to water input)	At or near soil surface for a significant duration during the frost free period (may decline during growing season due to evapo-transpiration, not drainage)
Dissolved O_2	Present	Absent or present
Origin of materials	Non-hydrophytic vegetation	Hydrophytic vegetation
Biota	Predominantly aerobic; fungal mycelia and/or actinomycetes commonly present, mites and springtails present at some time during year	Anaerobic (few flora or fauna observed beneath surface)

[1]Parenthesis indicate features or attributes of less significance.

[1]Names of soil taxa in parenthesis in this study refer to Soil Taxonomy (Soil Survey Staff 1975). The names of soil taxa preceding the parenthesis refer to the Canadian System of Soil Classification (CSSC 1978).

[2]Soil moisture regime (hygrotope; Pogrebnyak 1930, Krajina 1969), refers to the available soil water for plants. Nine classes (very xeric, xeric, subxeric, submesic, mesic, subhygric, hygric, subhydric, and hydric) on the relative and qualitative scale have been used in characterizing soil moisture regimes of ecosystems within the context of a biogeoclimatic subzone, representing a regional climate. Therefore, there is a unique set for each regional climate; e.g. a xeric class in one regional climate is not identical to the xeric class in another (drier, wetter, cooler or warmer) regional climate. This is in contrast to other schemes of characterization of soil moisture regimes which feature absolute scales (Soil Survey Staff 1975, CSSC 1978). A functional approach to the characterization of the nature of soil moisture regimes, has been proposed, i.e. by variations in available water as it changes with the seasons, and by relationships to climate and plant growth. This approach, based on Thornthwaite's concept (Thornthwaite 1948, Thornthwaite and Mather 1955, Thornthwaite *et al.* 1957) of balancing water added to ecosystems by precipitation against losses by evapotranspiration, was used by Major (1963), Soil Survey Staff (1975), Klinka *et al.* (1979), and is currently being tested at the Soil Science Department of the University of British Columbia.

F - (formultningsskiktet, fermented,[1] decayed materials): a master organic horizon characterized by more-or-less disintegrated plant residues[2] in which partial (rather than entire), macroscopically discernible vegetative structures are dominant.

The remains of more-or-less disintegrated organic materials may be identified as to their origin, but macromorphological decomposition is very apparent. The organic material may be comminuted by and may contain excrement of soil fauna and/or permeated by fungal hyphae. Roots are commonly present in the F horizons, particularly in forest ecosystems. Brownish-yellow to brownish-red macroscopically recognizable plant residues either predominate or are equivalent to organic fine substances[2]. The F horizons correspond partly to the O1 and O2 horizons (Soil Survey Staff 1975).

H - (humus materials): a terrestrial master organic horizon dominated by fine substances in which the original structures are macroscopically indiscernible.

The organic materials in the H horizons may be comminuted by and contain excrement of soil fauna, and/or permeated by fungal hyphae. Microbiotic activity is generally considered to be high. Black-brown to nearly black fine substances predominate over plant residues and rooting is generally common. Except for root residues, the plant residues are not recognizable macroscopically or only in small amounts. The H horizons correspond partly to the O2 horizons (Soil Survey Staff 1975).

O - ("organic materials")[3]; a semi-terrestrial master organic horizon.

The O horizons are characteristically associated with semi-terrestrial (wetland) ecosystems. Consequently, humus forming processes are influenced by a water table at or near the soil surface for a significant duration during the frost free period. The O horizons may also be found in terrestrial (upland) ecosystems in which compensating edaphic factors provide for non-freely drained organic horizons.

A - a master mineral horizon containing 17% or less organic carbon (about 30% organic matter) by weight. It is formed at or near the soil surface in the zone of leaching or eluviations of materials in solution or suspension, or of maximum in situ accumulation of organic matter or both (CSSC 1978).

[1]The strict definition of the term "fermented" implies processes not found in terrestrial humus forms and was originally used by Pasteur to designate anaerobic processes, or "life without oxygen". However, it has come to mean the decomposition of carbohydrates with the evolution of gas or the formation of acid or both (Waksman 1938) and is used extensively in literature pertaining to this horizon.

[2]Babel (1975) defined "plant residues" as coherent tissue parts which are recognizable, as such, microscopically; "organic fine substances" (hereafter, "fine substances"), refers to organic materials without definite microscopically recognizable structures. Cell wall fragments, small pieces of tissue comprised of a few cells, and fragments of fungal hyphae are included. The maximum size is approximately 100μ. Organic fine substances do not correspond entirely to colloidal substances, which have a maximim size of 1μ.

[3]The term "organic" should not be used as a synonym for this horizon.

Lowercase Suffixes

Lowercase suffixes are used to indicate variations in the range of properties of master horizons. Selected letters were not always connotative because of overlaps with lowercase suffixes for mineral horizons used by CSSC (1978). The use of duplicate letters with different meanings for organic and mineral horizons is clearly undesirable. Therefore, the following letters were chosen to apply to specific master organic horizons: o, v, q, a, r, and d. Lowercase suffixes may also be applied to any organic horizons without restrictions. The following Greek letters were chosen to represent these suffixes: β (beta), ι (iota), θ (theta), λ (lambda), and σ (sigma).

Organic horizons represent an entity completely different from mineral horizons. For this reason, and for eliminating any overlap with mineral horizon designations, it is proposed that letters of the Greek alphabet be used for all lowercase suffixes of master organic horizons. Such a proposal is included for consideration in the following definitions of subordinate horizons:

Lo - [original, new (Babel, 1975): proposed suffix - ν ("nu")]: an L horizon composed of newly accreted organic materials. These materials are usually loose, show no structural change, may be slightly discoloured, and are found on the ground surface, particularly during and after the growing season.

Lv - [variative (Babel, 1975): proposed suffix - ω ("omega")]: an L horizon composed of less recently accreted organic materials, usually showing some abiological disintegration and strong discolouration.

Fq - [non-connotative: proposed suffix - μ ("mu")]: an F horizon which is composed primarily of macroscopically recognizable, structurally well-preserved, plant residues. The materials have a matted banded fabric interwoven by abundant fungal hyphae. Faunal droppings or dropping residues are either absent or found only in small amounts (Figure 2).

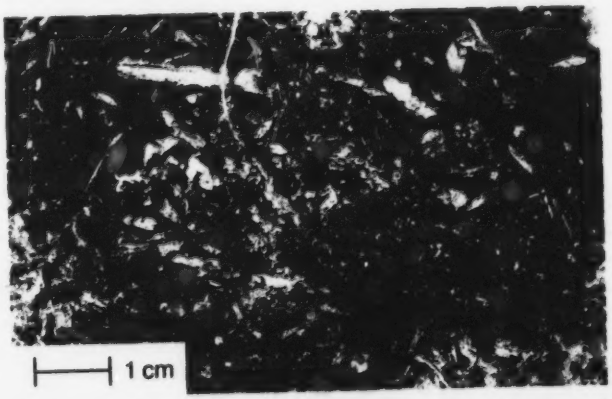

Figure 2. Poorly decomposed plant residues showing matted structure characteristic of an Fq horizon. Fungal mycelia are common throughout (Orthihemimor).

Fa - [non-connotative: proposed suffix - ϕ ("phi")]: an F horizon which is composed primarily of macroscopically recognizable plant residues which have been partly fragmented or comminuted by soil fauna. The materials are loose, not matted; fungal hyphae may be found in

small amounts. Faunal droppings and dropping residues are numerous and can be easily observed under magnification (Figure 3).

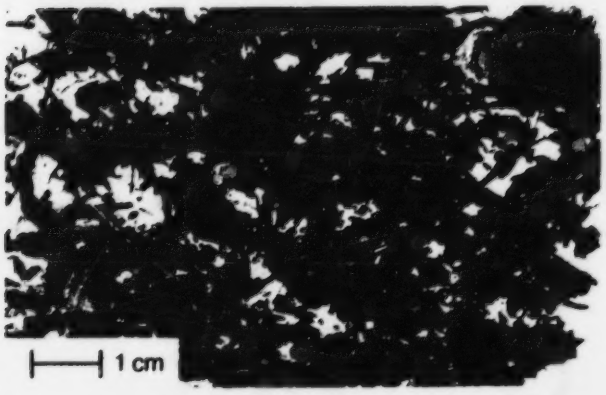

Figure 3. Partially decomposed plant residues showing very weak structure characteristic of an Fa horizon. Insect droppings are common throughout (Orthilepto-moder).

Faq- [proposed suffix -$\phi\mu$ ("phi, mu")]: an intergrade F horizon in which the materials show the presence of both fungal hyphae and faunal droppings. Droppings and dropping residues increase toward the lower part of the F horizon.

Babel (1975) proposed two subdivisions of the F horizon: Fr (a high ratio of plant residues to fine substances) and Fm (a medium ratio of plant residues to fine substances). In this study the discrimination between the Fq and Fa horizons was considered to be more significant than that based on the degree of decomposition. However, Fq, Fa and Faq horizons can be further subdivided according to the degree of decomposition by placing an arabic number after the respective lowercase suffix.

Hr - [residues: proposed suffix - ρ ("rho")]: an H horizon in which macroscopically recognizable plant residues from fine roots, wood and bark (rarely foliage) are present but do not predominate over fine substances. Yellow, brown and particularly red colours or their combinations often prevail.

Hd - [decomposed: proposed suffix - δ ("delta")]: an H horizon in which organic fine substances predominate with very few plant residues. Their colours are usually dark gray-brown or black.

Hda - [proposed suffix -$\delta\phi$ ("delta, phi")]: an H horizon in which organic fine substances predominate. Droppings resulting from active populations of soil fauna constitute almost the entire fabric.

The criteria proposed as guidelines to differentiate between the Hr and Hd horizons are presented in Table 2:

The following subordinate O horizons are used; the definitions are those of CSSC (1978):

Of - (fibric, Oi - Soil Survey Staff 1975): an O horizon that consists largely of materials that are readily identifiable as to botanical origin. It has 40% or more rubbed fiber by volume and a pyrophosphate index of 5 or more. If the rubbed fiber volume is 75% or more, the pyrophosphate criterion does not apply. Fiber is defined as the organic material retained on a 100-mesh sieve (0.15 mm) except for wood fragments that cannot be crushed in the hand and are larger than 2 cm along the smallest dimension. Rubbed fiber is the fiber that remains after rubbing a sample about 10 times between thumb and forefinger. Fabric materials are classified in the von Post scale of decomposition as class 1 to class 4.

Om - (mesic, Oe - Soil Survey Staff 1975): an O horizon consisting of partly decomposed materials which are at a stage of decomposition intermediate between fibric and humic materials. The mesic material is partly altered both physically and biochemically and is usually classified in the von Post scale of decomposition as class 5 or 6. The Om horizon does not meet the requirements of either the Of or Oh horizons.

Oh - (humic, Oa - Soil Survey Staff 1975): an O horizon in which the original organic materials have been transformed into humic materials. This horizon has the lowest amount of fiber, the highest bulk density and the lowest saturated water-holding capacity of the O horizons. It is very stable and changes very little physically or chemically with time unless it is drained. The rubbed fiber content is less than 10% by volume and the pyrophosphate index is 3 or less. Humic materials are usually classified in the von Post scale of decomposition as class 7 or higher and very occasionally as class 6.

TABLE 2. *Guidelines for the Differentiation of Hr and Hd Horizons*

Criteria	Hr	Hd
Materials	Fine substances predominate; macro and microscopically recognizable plant residues which disintegrate upon rubbing are common; dark coloured materials do not rub out on fingers	Fine substances clearly predominate; macroscopically recognizable plant residues are very few or absent; dark coloured materials rub out on fingers
Colour	At least one but often two hues redder than the underlying Hd, if present; colours often in the 2.5 YR hue, usually reddish brown	Not as red as the 2.5 YR.; usually very dark gray or nearly black
Structure	Generally fine to medium, blocklike	Generally massive or coarse, blocklike
Character	Slightly greasy when moist	Very greasy when moist
Bulk Density	Lower; similar to F horizons	Higher; generally less pore space than in F horizons

The following suffixes are used with the A master mineral horizon (the definitions and usage follow CSSC 1978):

Ah - an A horizon enriched with organic matter; it has a color value less than 4 and at least one unit lower than the underlying horizon and 0.5% more organic carbon than IC.

The Ah horizons can be further suffixed using e (eluviated, Ahe); j - (incipient, weakly expressed, Ahj): p - (disturbed by man's activities, Ahp); u - (disturbed by physical or faunal processes other than cryoturbation, Ahu); y - (cryoturbation, Ahy).

The use of Greek letters as lowercase suffixes are not restricted to any particular horizon or layer in the humus form profile. They are defined as follows:

β - [(beta) burned]: a horizon in which organic material is predominantly (>50% volume) or entirely charcoal. It is used with subordinate horizons of F, H and O master organic horizons (e.g. Fqβ) to indicate a predominance of charcoal materials, or with F (Fβ) and H (Hβ) alone, to indicate a "charcoal horizon".

ι - [(iota) incorporated inorganic materials]: an organic horizon in which organic materials are intermixed with mineral particles finer than 2 mm. It contains more than 17% but less than 35% organic carbon by weight. It is used with subordinate horizons of L, F, H, and O organic horizons (e.g. Hι)[1].

This intermixing of mineral particles with organic materials may result from several different processes (or their combination). The process should be indicated in the description using the following terms:

1. Colluvial
2. Eolian
3. Alluvial
4. Cryoturbation
5. Silvoturbation
6. Zoological

θ - [(theta) non-connotative]: an organic horizon which is comprised almost entirely of fungal mycelia. The colour is generally light grey; consistence and character are resilient and felty respectively. It is most often used with Fq horizons as partially decomposed plant residues are usually incorporated. It may be used with H master horizons where applicable.

λ - [(lambda) ligneous]: an organic horizon or layer in which organic material is predominantly (>50% by volume) wood in various stages of decomposition. It is used with subordinate horizons of L, F, H and O master organic horizons (e.g. Ofλ) to indicate a predominance of decaying wood, or with L (Lλ), F (Fλ), and H (Hλ) alone, to indicate a "decaying wood horizon".

σ - [(sigma) organic sediments]: an organic horizon that has developed by sedimentation usually containing fine (colloidal) organic materials. The suffix "ϕ" is used alone with H (Hϕ) and O (Oϕ) master organic horizons.

Table 3 gives a synopsis of horizons constituting a humus form profile and demonstrates how lowercase suffixes are used.

TABLE 3. *Synopsis of Organic Horizons Constituting a Humus Form Profile and Usage of Lowercase Suffixes*

Master Horizons	Restricted Lowercase Suffixes	Subordinate Horizons Unrestricted Lowercase Suffixes: Alone	In combination
L	Lo	Lλ , Lι	
	Lv		Lvι , Lvλ
F	Fq		Fqλ , Fqι , Fqβ , Fqθ
	Fa	Fλ , Fι , Fβ	Faλ , Faι , Faβ
	Faq		Faqλ , Faqι , Faqβ
H	Hr		Hrλ , Hrι , Hrβ
	Hd	Hλ , Hι , Hβ ,	Hdλ , Hdι , Hdβ
	Hda	Hθ , Hσ ,	Hdaλ , Hdaι , Hdaβ
O	Of		Ofλ , Ofι , Ofβ
	Om	Oσ	Omλ , Omι , Omβ
	Oh		Ohλ , Ohι , Ohβ

Horizon Combinations

Wilde (1958, 1966, 1971) introduced several terms for various general combinations of horizons included in the humus form profile. The following terms were adopted:

ectorganic - a part of a humus form formed by organic horizons, referred to collectively as ectorganic horizons;

endorganic - a part of a humus form formed by Ah horizons, referred to collectively as endorganic horizons;

holorganic - a humus form formed entirely by a combination of organic horizons; and

amphimorphic - a humus form formed by a combination of organic and mineral horizons.

The endorganic Ah horizons are enriched by residual, incorporated or infiltrated organic matter. Incorporation or intermixing may occur by several processes described previously. Infiltration of solid organic matter by rain water is a process by which great amounts are transported in all humus forms (Babel 1975). Podzolic B horizons that are enriched with precipitated humus materials due to the movement of dissolved organic matter along with sesquioxides are not considered endorganic.

[1]Hι horizon currently under study. Percent ash may prove to be a more meaningful distinguishing characteristic.

Humus Form Classification

The purpose of humus form classification is to organize knowledge about humus forms. The objective of the proposed taxonomic classification of humus forms is to create a hierarchy of classes which permit an understanding, within constraints of present knowledge, of the natural relationships between humus forms and the factors involved in their formation. In this first approximation the differentiae chosen for these classes are properties which are observable in the field or inferred from other properties observable in the field.

An attempt has been made to provide taxa for all humus forms known to occur in British Columbia and other places under the influence of comparable climates. However, some humus forms have not yet been adequately described and studied. When reasonable definitions and predictions from other workers were available, they were included in the system.Efforts were made to define each taxon explicitly, to identify meaningful and useful class boundaries and to select those properties which are useful as taxonomic differentiae.

The Outline of the System

A synopsis of the three-category taxonomic classification is presented in Table 4. In order of decreasing categorical rank and increasing number of differentiae, the categories are "humus form order", "humus form group" and "humus form subgroup." These are simplified in the text to "order", "group" and "subgroup", respectively.

Categories

The attributes which were considered to result from the genesis of humus forms were selected for the characterization of orders and groups; whereas those thought to be important to plant growth but of less significance to genesis were selected for subgroups and phases.

Thus, the taxonomic differentiae for orders and groups are based on the presence or absence of diagnostic organic and mineral horizons (*i.e.* a characteristic humus form profile), relative thickness of the horizons,

TABLE 4. *A Synopsis of Humus Form Taxa*

Order	Group	Subgroup
1. Mor	11. Velomor	111. Orthivelomor
		112. Neovelomor
		113. Amphivelomor
	12. Xeromor	121. Orthixeromor
		122. Lignoxeromor
		123. Amphixeromor
	13. Hemimor	131. Orthihemimor
		132. Mycohemimor
		133. Lignohemimor
		134. Amphihemimor
	14. Hemihumimor	141. Orthihemihumimor
		142. Mycohemihumimor
		143. Lignohemihumimor
		144. Granulohemihumimor
		145. Residuohemihumimor
		146. Amphihemihumimor
	15. Humimor	151. Orthihumimor
		152. Mycohumimor
		153. Lignohumimor
		154. Granulohumimor
		155. Residuohumimor
		156. Amphihumimor
	16. Hydromor	161. Orthihydromor
		162. Residuohydromor
		163. Hemihydromor
		164. Saprihydromor
	17. Histomor	171. Orthihistomor
		172. Fermihistomor
		173. Saprihistomor
		174. Hydrohistomor
2. Moder	21. Velomoder	211. Orthivelomoder
		212. Minerovelomoder
		213. Amphivelomoder
	22. Xeromoder	221. Orthixeromoder
		222. Mineroxeromoder
		223. Amphixeromoder
	23. Mormoder	231. Orthimormoder
		232. Humimormoder
		233. Mineromormoder
		234. Amphimormoder
	24. Leptomoder	241. Orthileptomoder
		242. Hemileptomoder
		243. Mineroleptomoder
		244. Amphileptomoder
	25. Mullmoder	251. Orthimullmoder
		252. Vermimullmoder
		253. Rhizomullmoder
	26. Hydromoder	261. Orthihydromoder
		262. Ectohydromoder
		263. Saprihydromoder
	27. Histomoder	271. Orthihistomoder
		272. Fibrihistomoder
		273. Saprihistomoder
		274. Hydrohistomoder
3. Mull	31. Rhizomull	311. Orthirhizomull
		312. Crustorhizomull
		313. Vermirhizomull
		314. Xerorhizomull
	32. Vermimull	321. Orthivermimull
		322. Microvermimull
		323. Macrovermimull
	33. Hydromull	331. Orthihydromull
		332. Humihydromull
		333. Saprihydromull
	34. Saprimull	341. Orthisaprimull
		342. Parasaprimull
		343. Histosaprimull
		344. Humisaprimull
		345. Hydrosaprimull

and features of humus forms that are indicative of the dominant sets of humus-forming processes. Orders are differentiated by horizon combinations and by the kind of F horizon in the humus form profile inferred to be indicative of essential differences in the nature of humus formation (*i.e.* mineralization (decomposition of fresh organic or synthesized humus materials into simple soluble compounds); humification (a synthesis of humus materials); and the kind and degree of incorporation of humus materials with mineral soil.

The differentiae for groups vary with the order. In general, they provide for segregation along the soil moisture gradient into xeromorphic, mesomorphic and hydromorphic humus forms, and according to kind and arrangement of horizons. These differentiae were selected to emphasize genetic homogeneity.

The subgroups were intended to place together humus forms that have close similarities in kind and fabric of materials and horizon sequence. There are three kinds of subgroups:

1. subgroups that conform to the central concept of the group;
2. subgroups that deviate from the central concept by having aberrant, apparently genetically subordinate features, and;
3. subgroups having properties intergrading to other subgroups or groups.

Phases are used to provide flexibility in the system by taking into consideration properties other than those used to differentiate the taxa. These properties generally relate to plant growth or other management interpretations. Phases of subgroups, groups and orders may be recognized.

Nomenclature

Nomenclature for the proposed classification was developed following the principles applied by Soil Survey Staff (1975).The name of each taxon indicates its position in the classification, as well as its class in all categories of which it is a member. Either existing names were used or new ones coined using formative elements and adjectives derived mostly from Greek or Latin roots. These formative elements and adjectives suggest prominent properties, preferably those used as taxonomic differentiae.

Three internationally recognized terms form the taxa at the order category level: Mor, Modor and Mull (Table 4). Mor and Mull were described by Müller (1878). The term Moder was introduced at a meeting of workers studying humus forms in Eisenach in 1904 (Hartmann 1952).

Names of groups are formed by adding a formative element to the name of the order (Table 5); names of subgroups are formed by adding a formative element (Table 6) to the name of the group. The formative element "orthi" is used for the subgroup that represents the central concept of the group. Each "orthi" subgroup exhibits a clear expression of all diagnostic properties of the order and group to which it belongs; therefore, "orthi" subgroups have neither transitional properties to another subgroup nor aberrant properties that require special recognition. Other formative elements designate the subgroups that have, in addition to the properties of their group, some aberrant properties requiring special recognition. The subgroups presented in the synopsis (Table 4) are not the only possible subgroups in the classification. Intergrade subgroups may be recognized, *i.e.* those having properties of another subgroup in the same group. They are named by prefixing two formative elements used for the subgroups to the group name. Thus, the Lignohumimors which feature abundant fungal mycelia or a mycelial layer are called Myco-Lignohumimors. An illustration of the nomenclature as it relates to the different categories in the system is as follows:

Mor ..... Order
Hemimor ..... Group
Orthihemimor ..... Subgroup

Names of phases are polynomial. They consist of one or more modified Latin or Greek adjectives preceding a subgroup, group or order name (Table 7). This list of adjectives indicates properties requiring recognition for interpretative purposes. For example, Humimors under the influence of a subalpine-boreal climate feature a high bulk density, and are thus called Compactic Humimors. If they are also influenced by litterfall of yellow cedar, rich in macronutrients, they have a higher base saturation than that commonly found for Humimors; hence, they are called Eutrophic Compactic Humimors.

Adjectives which describe formative elements used in the naming of groups and subgroups can be also used for phasing. Thus, one can form the term "Lignic Mor phase" to refer to all Mors with properties which are influenced by a high amount of decaying wood. To use "lignic" in this way is equivalent to creating an informal group (taxon). Adjectives in names of phases are arranged according to interpretative significance. Redundancy in names of phases of subgroups should be avoided. If a property is specified for a subgroup, which may or may not be used in its name, it should not be used in a phase name. The first letters in names of all taxa and their phases are capitalized.

The taxonomic class of a specific humus form can firstly be determined by using the keys, figures of characteristic humus form profiles and definitions that follow. One should subsequently consult the definition of the taxon with which one is concerned. The definition of the first group with the formative element "orthi" is followed by a description of the humus form profile. Analytical data of some humus forms representing groups and orders is given in the section entitled "Testing of the Taxonomy".

TABLE 5. *Formative Elements in Names of Groups*

Formative element	Adjective	Connotation
Hemi	Hemic	*(Hemi)* half; implying intermediate decomposition. It designates terrestrial Mors that have prominent F horizons.
Histo	Histic	*(Histos)* tissue; implying the least and intermediate decomposition in the semi-terrestrial environment. It designates the Mors and Moders that feature well developed Of or Om horizons.
Humi	Humic	Humus; implying the dominant presence of organic fine substances. It designates the terrestrial Mors that have a prominent H horizon.
Hydro	Hydric	*(Hydor)* water; designates the humus forms formed under the influence of hygric or subhydric soil moisture regimes.
Lepto	Leptic	*(Leptos)* thin, fine; refers to small droppings, dropping residues and exoskeletons of soil mesofauna characteristic of the Fa horizon. It is used to designate the representative group of Moders.
Mor	Moric	Implying properties of Mors.
Mull	Mullic	Implying properties of Mulls.
Rhizo	Rhizic	*(Rhiza)* root; refers to the rhizogenous Ah horizon in Mulls. These Ah horizons are formed from the decomposition of roots of herbaceous plants, mainly grasses.
Sapri	Sapric	*(Sapros)* rotten; implying most advanced decomposition. It designates semi-terrestrial Mulls with an Oh (or Oh$_t$) horizon formed under the influence of a sybhydric or hydric soil moisture regime.
Velo	Velic	*(Velum)* veil, curtain or covering; denotes thin ectorganic horizons dominated by litter materials.
Vermi	Vermic	*(Vermis)* worm; refers to the zoogenous Ah horizon in Mulls. Earthworms *(Lumbricidae)* are the representative soil fauna.
Xero	Xeric	*(Xeros)* dry; implying a xeric soil moisture regime. Xeric may be used as the more general class including very xeric, xeric and subxeric classes of moisture regime.

TABLE 6. *Formative Elements in Names of Subgroups*

Formative element	Adjective	Connotation
Amphi	Amphic	*(Amphi)* of both kinds; designates amphimorphic Mors and Moders that have well developed endorganic horizons.
Crusto	Crustic	*(Crust)* hard, crisp; designates Rhizomulls that have, in the upper portion of the humus form profile, dry, brittle and firm fabric.
Ecto	Ectic	Ectorganic; indicates Hydromoders lacking Ah horizons.
Fermi	Fermic	*(Fermentatum)* fermented; implying anaerobic decomposition. It designates the Histomors that feature a well developed Om horizon.
Fibri	Fibric	*(Fibra)* fiber; designates the presence of a well developed Of horizon in the humus form profiles of Histomoders.
Granulo	Granulic	*(Granulum)* grains, granules; designates the Mors that have a friable, moderately to strongly granular H horizon.
Hemi	Hemic	*(Hemi)* half, cf. Table 5; implying intermediate decomposition. It designates Hydromors and Leptomoders that feature a well developed F horizon.
Histo	Histic	*(Histon)* woven fabric, tissue, cf. Table 5; implying the least and intermediate decomposition in the semi-terrestrial environment. It designates Saprimulls that feature a well developed Of or Om horizon.
Humi	Humic	Humus; implying the dominant presence of colloidal organic substances. It designates the terrestrial Mors that have a prominent H horizon.
Hydro	Hydric	*(Hydor)* water, cf. Table 5; designates intergrade subgroups of all orders formed in a semi-terrestrial environment (hygric to hydric soil moisture regime).

TABLE 6. *Formative Elements in Names of Subgroups* — Continued

Formative element	Adjective	Connotation
Ligno	Lignic	*(Lignum)* wood; designates Mors that have more than 50% decaying wood by volume within the humus form profile.
Macro	Macric	*(Makros)* long; designates the zoogenous Ah horizons of Vermimulls that have moderate to strong, medium to very coarse granular structure.
Micro	Micric	*(Mikros)* small; designates the Ah horizons of Vermimulls that have moderate to strong, very fine to fine, granular structure.
Minero	Mineric	*(Mineralis)*; designates Xeromoders, Mormoders and Leptomoders which contain significant amounts of intermixed mineral particles, as indicated by Fat , Hdt or Hdat horizons.
Myco	Mycic	*(Mukes)* mushroom, mucor; designates Mors that have a horizon comprised almost entirely of fungal mycelia.
Orthi	Orthic	*(Orthos)* true; designates the subgroup that is thought to typify the group.
Para	Paric	*(Para)* beside; designates Saprimulls that lack Oht or Ahg horizons.
Residuo	Residuic	Residues; designates Mors in which an Hr horizon, characterized by the presence of fine plant (mainly root) residues, is dominant in the humus form profile.
Rhizo	Rhizic	*(Rhizo)* root, cf. Table 5; designates Mullmoders that have rhizogenous Ah horizons.
Sapri	Sapric	*(Sapros)* rotten, cf. Table 5; designates the subgroups of Hydromors, Histomors, Hydromoders, Histomoders, and Hydromulls, that feature a well developed Oh horizon.
Neo	Neoic	*(Neos)* recent, young; implying initial humus formation. It designates Velomors that consist entirely of litter materials.
Vermi	Vermic	*(Vermis)* worm, cf. Table 5; refers to a zoogenous Ah horizon in the humus form profile of Rhizomulls.
Xero	Xeric	*(Xeros)* dry, cf. Table 5; designates Rhizomulls that have formed in semi-arid (to subhumid) climates in xeric (very xeric, xeric or subxeric) ecosystems.

TABLE 7. *Adjectives in Names of Phases and Their Meaning*[1]

Adjective	Connotation
Acidic	*(Acidus)* acid; designates humus forms that have high acidity.
Aeric	*(Aer)* air; designates humus forms that have a low bulk density (high porosity).
Albic	*(Albus)* white; designates humus forms that are underlain by a well developed Ae horizon.
Charcic	Charcoal; designates humus forms that possess significant amounts (>20% by volume) of charcoal.
Clastic	*(Clastos)* broken; designates humus forms that contain many (>20% by volume) coarse fragments.
Compactic	*(Compactus)* concentrated; designates humus forms that have a high bulk density (low porosity).
Crustic	*(Crusta)* hard, crisp; designates humus forms in which the upper horizons have a dry, brittle and firm fabric.
Dystrophic	*(Dys...trophe)* ill...food; infertile; designates humus forms that are nutrient deficient.
Eutrophic	*(Eu...trophe)* well...food; fertile; designates the humus forms that are nutrient rich.
Hygric	*(Hygros)* wet; designates humus forms that feature subsurface water flow (seepage) within the humus form profile.
Lignic	*(Lignum)* wood, cf. Table 6; designates humus forms possessing significant amounts (>50% by volume) of decaying wood.
Ochric	*(Ochros)* pale; designates humus forms that have an Ah horizon with a moist colour value ≥ 3.
Pachic	*(Pachys)* thick; designates thick humus forms.
Pellic	*(Pellos)* dusky, dark coloured; designates humus forms that have an Ah horizon with a moist colour value <3 and low chroma.

TABLE 7. *Adjectives in Names of Phases and Their Meaning*[1] - Continued

Adjective	Connotation
Rhodic	*(Rhodon)* rose; designates residuic Mor humus forms that have a prominently reddish coloured Hr horizon, usually derived from decaying wood materials.
Ruptic	*(Ruptus)* burst or broken; designates humus forms that have a broken horizon(s) in the control section.
Spodic	*(Spodos)* wood ash; designates humus forms that have well developed podzolic horizons, high in organic matter content, directly underlying entorganic horizons.
Tenuic	*(Tenuis)* thin; designates thin humus forms.
Terric	*(Terric)* earth; an inorganic substance; designates humus forms that have a mineral horizon in the humus form profile.
Turbic	*(Turbo)* stir up; designates humus forms that have a truncated profile or have been markedly disrupted by physical processes.
Ustic	*(Ustus)* burnt; designates humus forms that have been recently affected by fire and feature a black, crusty (hard, brittle and tenacious) surface horizon.

[1]These adjectives indicate non-conformity in properties relative to the central concept of a formal taxon. The list is not exhaustive and will be enlarged as required.

Description of Taxa

Key to Orders

1a. Well aerated, terrestrial humus forms that can be temporarily saturated (xeric to hygric moisture regimes)
  2a. Ectorganic horizons are predominant in the humus form profile; both F and H horizons are each > 1 cm thick
    3a. F horizons are predominantly mycogenous (Fq)
      Mor
    3b. F horizons are predominantly zoogenous (Fa) or zoogenous-mycogenous (Faq)
      Moder
  2b. Ectorganic horizons are very thin and insignificant in the humus form profile; both F and H horizons are each < 1 cm thick; well developed rhizogenous or zoogenous Ah horizons are > 2 cm thick
    Mull

1b. Poorly aerated, terrestrial to semi-terrestrial humus forms influenced by prolonged or permanent saturation (hygric to subhygric moisture regimes)
  4a. O horizons comprise > 50% of thickness of organic horizons in the humus form profile
    5a. Of horizons are dominant in the humus form profile
      Mor
    5b. Om horizons are dominant in the humus form profile
      Moder
    5c. Oh or Oh$_t$ horizons are dominant in the humus form profile
      Mull
  4b. O horizons comprise < 50% of thickness of organic horizons in the humus form profile
    6a. Ectorganic horizons generally exceeding 2 cm thickness are significant in the humus form profile
      7a. Fq horizon present; Ah or Ahg horizons are absent or < 5 cm thick
        Mor
      7b. Fa horizon present. Ah or Ahg horizons are > 5 cm thick
        Moder
    6b. Ectorganic horizons are very thin and insignificant in the humus form profile (generally < 2 cm thick). Well developed Ahg or Ah horizons > 5 cm thick dominate the profile
      Mull

1. Mor Order

The Mor order encompasses the least biologically active humus forms of the three orders. It is related to the Moder order in that terrestrial humus forms of both orders often possess similar master horizon sequences. This has led to the grouping of these two major humus forms into a single humus formation, "mor", in English and American classifications. They are, however, differentiated on the basis of fungi being dominant in the F horizon of Mors, while soil fauna are dominant in the F horizon of Moders. These genetic differences are reflected in their respective micro- and macromorphology (Babel 1975).

The diagnostic F horizon (in Histomors, the diagnostic horizon is Of), is often relatively thick, reflecting the slow decomposition processes taking place (Babel 1975). It is composed primarily of partly decomposed, structurally well preserved plant residues. These materials have a matted, plate-like fabric, interwoven by fungal hyphae. Decomposition of plant residues is carried out primarily by cellulose-decomposing fungi (Waksman 1938). Bacteria play a minor role because of their intolerance to acid conditions typical of Mors. Acid-tolerant protozoa and soil fauna contribute to decomposition in a limited degree, the latter restricted generally to mites, collembola, and enchytraeids (Pritchett 1979). As a result, very few faunal droppings are present (Babel 1975, Kubiena 1953, Bernier 1968). In addition to litter materials, fine

roots and their residues constitute a significant portion of the plant residues of the F horizon. Often they form a dense network that permeates the remaining materials. This feature is more commonly associated with Mors than other humus forms (Babel 1975).

Other organic horizons found in Mors include L and H (in Histomors and some Hydromors these are Of, Om and Oh). Due to the small degree of mineral grain mixing by mor-inhabiting fauna, H horizons are generally free of mineral particles (Barratt 1964). However, significant quantities of mineral particles may be intermixed on sites where humus forms are subjected to repeated disturbance or to geomorphic processes of degradation or aggradation. F horizons may be affected in a similar way.

Mor humus forms generally consist entirely of ectorganic horizons. However, "amphi" subgroups have an underlying mineral horizon enriched in humus in the humus form profile (Bernier 1968, Babel 1975). This horizon contains humus materials infiltrated from the ectorganic horizons as solid particles in suspension. Both its upper and lower boundaries are abrupt. The humus is not incorporated by the action of soil fauna.

Chemical properties of Mors indicate that the humus materials are generally very acid to acid. High C/N values and high cation exchange capacities (ammonium acetate method) are also typical. This suggests that they represent a storage of nutrients which are slowly released and made available to plants. Furthermore, the acid humus materials contribute to translocation of inorganic constituents from the upper to lower solum.

Mors develop primarily under boreal forests but also elsewhere where climatic and/or edaphic conditions are unfavourable for the development of the more biologically active humus forms.

The Mor order is subdivided into seven groups on the basis of soil moisture regimes and the kind and arrangement of horizons (Table 8, Figure 5).

TABLE 8. *Synopsis of Taxa of the Mor Order*

Group	Subgroup
11. Velomor	111. Orthivelomor
	112. Neovelomor
	113. Amphivelomor
12. Xeromor	121. Orthixeromor
	122. Lignoxeromor
	123. Amphixeromor
13. Hemimor	131. Orthihemimor
	132. Mycohemimor
	133. Lignohemimor
	134. Amphihemimor
14. Hemihumimor	141. Orthihemihumimor
	142. Mycohemihumimor
	143. Lignohemihumimor
	144. Granulohemihumimor
	145. Residuohemihumimor
	146. Amphihemihumimor
15. Humimor	151. Orthihumimor
	152. Mycohumimor
	153. Lignohumimor
	154. Granulohumimor
	155. Residuohumimor
	156. Amphihumimor
16. Hydromor	161. Orthihydromor
	162. Residuohydromor
	163. Hemihydromor
	164. Saprihydromor
17. Histomor	171. Orthihistomor
	172. Fermihistomor
	173. Saprihistomor
	174. Hydrohistomor

TABLE 8. *Synopsis of Taxa of the Mor Order* - Continued

Key to Groups of the Mor Order

1a. Well aerated Mors that can be temporarily saturated by water

2a. L horizons comprises > 80% of the thickness of ectorganic horizons

Velomor

2b. L horizons comprises < 80% of the thickness of ectorganic horizons

3a. Prolonged moisture deficiency in the growing season (xeric moisture regimes)[1]

Xeromor

3b. None or short term moisture deficiencies

4a. H horizon comprises < 30% of the combined thickness of Fq and H horizons

Hemimor

4b. H horizon comprises > 30% of the combined thickness of Fq and H horizons

5a. H horizon comprises > 30% but < 70% of the combined thickness of Fq and H horizons

Hemihumimor

5b. H horizon comprises > 70% of the combined thickness of Fq and H horizons

Humimor

1b. Poorly aerated Mors; prolonged or permanent saturation by water (hygric to subhydric moisture regimes)[2]

[1]Xeric (very xeric, xeric, subxeric) moisture regimes: inputs of water by precipitation are removed from the soil very rapidly in relation to other ecosystems. Soils are characterized by a low water storage capacity, which may be attributed to coarse texture, shedding slope position (physiographic prominences, steep upper slopes) or very shallow depth, either individually or in combination.

[2]Hygric moisture regime: water is removed from the soil slowly in relation to supply so that the soil remains wet for most of the growing season. Permanent seepage is 30 to 60 cm below the soil surface.
Subhydric moisture regime: water is removed from soil so slowly that the water table remains at or near the surface for the greater part of the year. Permanent seepage is less than 30 cm below the surface, or there is a stagnant or fluctuating water table.

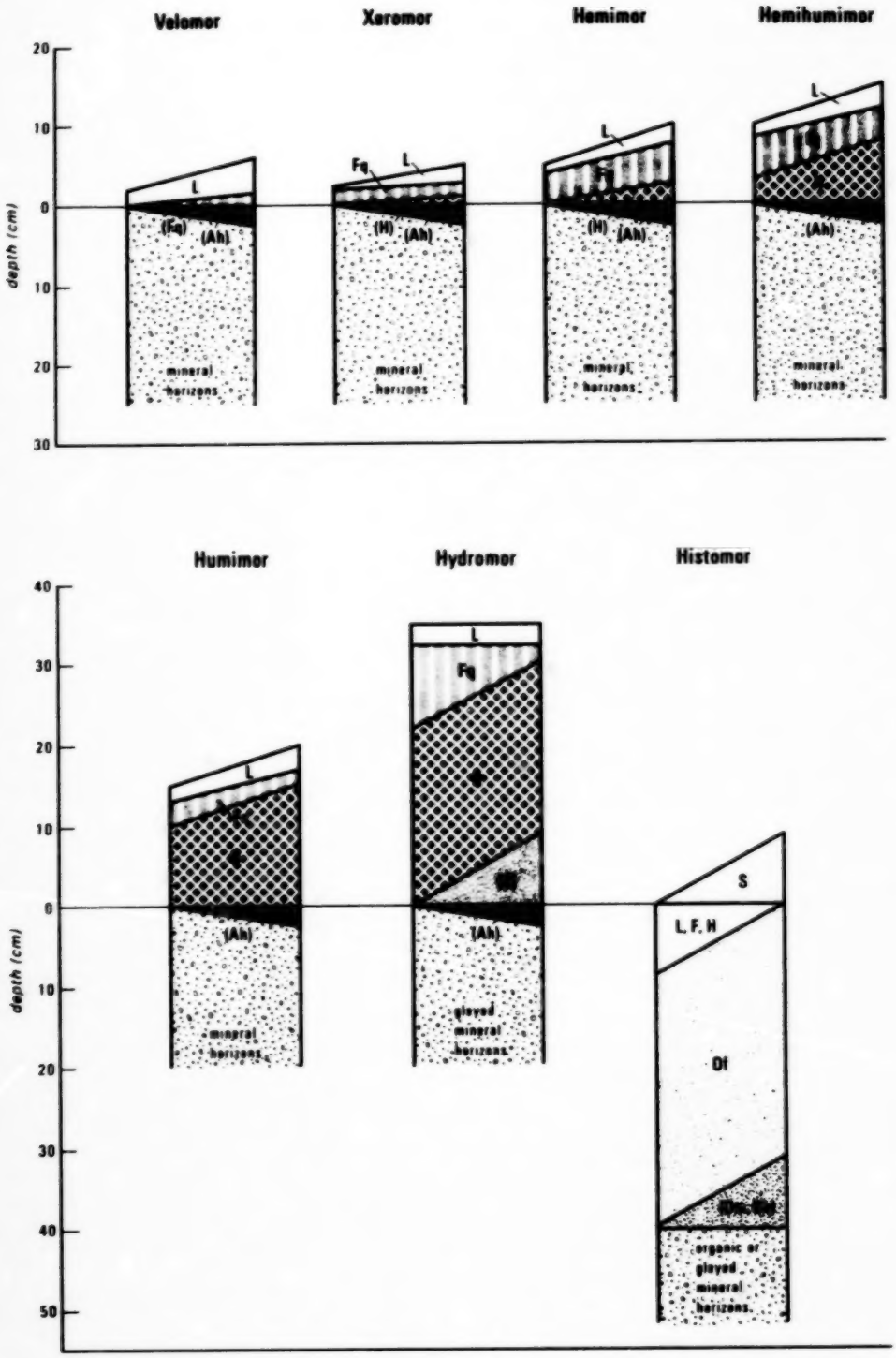

Figure 5. Characteristic humus form profiles of groups of the Mor order represented by *orthi* subgroups.

6a. Fq and/or H horizons comprise > 50% of the thickness of organic horizons in the humus form profile; endorganic horizons are lacking
Hydromor

6b. O horizons comprise > 50% of the thickness of organic horizons in the humus form profile; the Of horizons comprise > 50% of the combined thickness of these O horizons
Histomor

11. Velomor

[n.n.; Kubiena 1953: Raw Soil Humus (in part); Wilde 1958: Velum (in part); Wilde 1966, 1971: Velor (in part)]

Characteristic humus form profile: L, (Fq)[1], (Ah)

Velmors consist essentially of an accumulation of undecomposed, usually coniferous forest litter. Specifically, L horizons comprise >80% of the thickness of ectorganic horizons. They have single particle structure, loose consistency and acerose character; their thickness generally ranges from 1 to 10 cm. H and endorganic horizons are usually absent.

These humus forms are considered to represent the early stages of development, either primary or secondary, of Mors, or eventually Moders. They show a low degree of decomposition which, in forested ecosystems, is attributed to a high amount of litterfall and a climatic environment of young dense canopied coniferous stands. Decomposition increases following the opening of the canopy which, in turn, renders more favourable conditions for the synthesis of humus materials.

Velomors have been relatively little studied; thus, the proposed subgroups are tentative.

Key to subgroups

2a1. Velomors that have a thin Fq horizon, which comprise < 20% of the ectorganic horizons
Orthivelomor

2a2. Velomors that consist entirely of litter materials
Neovelomor

2a3. Velomors that have a continuous Ah horizon > 2 cm thick in the humus form profile
Amphivelomor

12. Xeromor

Duchaufour 1960 [n.n.; Wilde 1958: Crust Mor; Wilde 1966, 1971: Crustar; Bernier 1968: Licheno Fibrimor; Hartmann 1952: Waldtrockentorf (in part)]

Characteristic humus form profile: L, Fq, (H), (Ah)

Xeromors are Mors that are influenced by prolonged moisture deficiencies during the growing season resulting primarily from climatic and/or edaphic limitations.

The humus form profile typically has a thin L horizon derived primarily from coniferous needles and lichen and bryophyte tissues. The underlying F horizon has a characteristic compact matted structure, and firm to friable consistence (consistence varies with moisture status). Fungal mycelia are usually present but in many cases are very fine and light coloured, making them difficult to see with the naked eye. H horizons are either thin or missing entirely. All horizons are generally dry or desiccated for much of the growing season, except for relatively short durations following precipitation. When dry, the morphology is typically firmly consolidated and crust-like. Xeromors are generally < 5 cm thick.

Xeromors develop under prolonged moisture deficiencies and, as a result, decomposition of organic matter by biological agents tends to be suppressed. Ecosystems which support Xeromors often experience a history of repeated fire (both underburns and crown fires). This repeated destruction of the humus impedes the build-up of organic horizons. In addition, production of litter is often sparse on these sites as a result of the low ecosystem productivity.

Xeromors are found most frequently in ecosystems with extremely shallow or very coarse textured soils. Forest stands are generally open or lacking entirely.

Key to subgroups

3a1. Xeromors that conform to the central concept of the group
Orthixeromor

3a2. Xeromors that have > 50% by volume of decaying wood in the humus form profile
Lignoxeromor

3a3. Xeromors that have a continuous Ah horizon > 2 cm thick in the humus form profile
Amphixeromor

Description of an Orthixeromor

The following description of a humus form profile has the characteristics of the central concept of Xeromors. The profile is located near Blue River in the Kamloops Forest Region. The ecosystem is classified as the Picea (engelmannii) - Pinus (contorta) - Vaccinium (membranaceum) - Cladonia Association on a very shallow, loamy-skeletal Orthic Humo-Ferric Podzol formed on colluvial materials overlying granitic bedrock.

Horizon	Depth (cm)	Description
L	3.5-2.5	Coniferous needles and lichens; desiccated; single-particle; loose; acerose; no roots; no visible biota; abrupt, smooth boundary.
Fq	2.5-1	Desiccated; compact matted, firm; crusty; plentiful, fine roots; common, fine, coarse fragments; few, white mycelia; abrupt, smooth boundary.
Hd	1-0	Desiccated; very dary gray (10YR 3/1 m); plentiful, fine roots; common, fine, coarse fragments; abundant, white mycelia; abrupt, wavy boundary.

13. Hemimor

[n.n.; Romell and Heiberg 1931: Fibrous Duff; Hoover and Lunt 1952: Thin Mor, Imperfect Mor; Kubiena 1953: Raw Humus; Wilde 1958: Ligno-Mycelial Mor,

[1]Parenthesis indicate features or attributes of less significance.

Lean Mor (in part); Wilde 1966, 1971,: Lentar (in part); Bernier 1968: Fibrimor (in part); Hartmann 1952; Waldtrockentorf (in part)]

Characteristic humus form profile: L, Fq, (H), (Ah)

Hemimors are Mors that have prominent Fq horizons relative to other organic horizons in the humus form profile. Specifically, the H horizon comprises < 30% of the combined thickness of the F and H horizons.[1]

The diagnostic Fq horizon is comprised of partially decomposed leaves and needles, as well as relatively significant quantities of fine root residues (Babel 1975). Fungal hyphae are common. A non-compact to compact matted structure is typical. Faunal droppings are rarely observable. H horizons are relatively thin or even absent. Hemimors commonly range from 5 to 10 cm in thickness.

The dominant Fq horizon implies nutrient conservation resulting from slower rates of decomposition of litter, and of synthesis of humus materials. It may also reflect the maturity of the humus form. In ecosystems which have been disturbed by fire, there has been insufficient time for the build-up of a well developed H horizon.

Hemimors are found in a wide range of ecosystems. They are particularly prevalent in dry boreal climates or under young coniferous forests.

Key to subgroups

4a1. Hemimors that conform to the central concept of the group

Orthihemimor

4a2. Hemimors that have a horizon comprised almost entirely of fungal mycelia (designated by "θ" suffix)

Mycohemimor

4a3. Hemimors that have > 50% by volume of decaying wood in the humus form profile

Lignohemimors

4a4. Hemimors that have continuous Ah horizons > 2 cm thick in the humus form profile

Amphihemimor

Description of an Orthihemimor

The following description of a humus form profile has the characteristics of the central concept of Hemimors. The profile is located near Clearwater in the Kamloops Forest Region. The ecosystem is classified as the Abies (lasiocarpa) & (Picea (engelmannii)) - Rhododendron (albiflorum) - Valeriana (sitchensis) Association on a loamy Orthic Humo-Ferric Podzol formed on morainal materials overlying phyllite bedrock.

Horizon	Depth (cm)	Description
L	7-6	Coniferous needles; dry; weak, non-compact matted; loose; acerose; no roots; no visible biota; abrupt, smooth boundary.
Fq	6-2	Moist; brown (7.5 YR 3/2 m); compact matted; strongly tenacious; felty; plentiful, fine roots; common, pale yellow and white mycelia; abrupt, smooth boundary.
Hd	2-0	Moist; very dark gray (10 YR 3/1 m); massive; pliable; abundant, fine roots; common, fine charcoal; common, pale yellow mycelia; abrupt, smooth boundary.

[1]The value of 30% is a modification of Bernier's "< 10%" criterion for Fibrimor.

14. Hemihumimor

[n.n.; Hoover and Lunt 1952: Thick Mor (in part); Kubiena 1953: Raw Humus (in part); Wilde 1966, 1971: Lentar (in part); Bernier 1968: Humi-Fibrimor (in part); Hartmann 1952: Waldtrockentorf (in part)]

Characteristic humus form profile: L, Fq, H, (Ah)

Hemihumimors are Mors that have both Fq and H horizons which show no particular dominance in the humus form profile. Specifically, the thickness of the H horizon comprises between 30 and 70% of the combined thickness of F and H horizons.

The Fq horizon is comprised of partially decomposed litter and fine root residues. Both the Fq and the L horizons typically have a non-compact to compact matted structure. Fungal mycelia are commonly present. They are generally concentrated in the F horizon but sometimes permeate the entire humus profile. Roots are plentiful or abundant in all or part of the profile. Faunal droppings are rarely observable in the Fq horizon. Fine droppings may be observed under magnification in the H horizon and occasionally constitute a significant portion of the fabric (Babel 1975).

The similarity of thickness of the Fq and H horizons implies rates of decomposition and humification of organic materials intermediate between that of Hemimors and Humimors. The stages of development of humus formation may also be reflected. Thus, Hemihumimors may represent in some cases an intermediate successional stage advancing towards a Humimor.

Hemihumimor is a modified consolidation of Bernier's Fibri-Humimor and Humi-Fibrimor groups. His two taxa representing a transition between Hemimors (Fibrimors) and Humimors were consolidated into one taxon on the basis of low correlation with chemical properties.

Key to subgroups

5a1. Hemihumimors that conform to the central concept of the group

Orthihemihumimor

5a2. Hemihumimors that have a horizon comprised almost entirely of fungal mycelia (designated by "θ" suffix)

Mycohemihumimor

5a3. Hemimors that have > 50% by volume of decaying wood in the humus form profile

Lignohemihumimor

5a4. Hemimors that have friable H horizons with a moderate to strong granular structure

Granulohemihumimor

5a5. Hemimors that have Hr > Hd horizons

Residuohemihumimor

5a6. Hemimors that have continuous Ah horizons >2 cm thick in the humus form profile
Amphihemihumimor

Description of an Orthihemihumimor

The following description of a humus form profile has the characteristics of the central concept of Hemihumimors. The profile is located near Clearwater in the Kamloops Forest Region. The ecosystem is classified as the Tsuga (heterophylla) - Thuja (plicata) - Hylocomium (splendens) - Pleurozium (schreberi) Association on a loamy-skeletal Brunisolic Gray Luvisol formed on morainal materials over granitic bedrock.

Horizon	Depth (cm)	Description
L	5-4	Needles and feather mosses; dry; moderate, compact matted; loose; acerose; few, very fine roots; no visible biota; abrupt, smooth boundary.
Fq	4-2	Moist; dark brown (7.5 YR 3/2 m); moderate, compact matted; moderately tenacious; fibrous; plentiful, very fine roots; common, very fine, white mycelia; abrupt, smooth boundary.
Hd	2-0	Moist; dark brown (7.5 YR 3/2 m); moderate, fine, granular; pliable; plentiful, fine roots; common, fine decaying wood and charcoal; few, very fine, white mycelia; clear, wavy boundary.

15. Humimor

Bernier 1968 [n.n.; Romell and Heiberg 1931: Greasy Duff; Hoover and Lunt 1952: Thick Mor (in part); Hartmann 1952: Anaerober Waldnasstorf (in part)]

Characteristic humus form profile: L, Fq, H, (Ah)

Humimors are Mors that have more prominent H horizons than F horizons. Specifically, H horizons comprise over 70% of the combined thickness of F and H horizons.

The F horizon typically shows a non-compact to compact matted structure. The diagnostic H horizon is generally massive with a greasy character when wet, or friable with a fine blocky or granular structure when moist. Roots are common to abundant in all or part of the humus form profile. Fungal hyphae are always present and are usually concentrated in the F horizon, although they may occur throughout the profile. Faunal droppings are rarely observable in the F horizon. Tiny spherical or cylindrical droppings may be observed under magnification in the H horizon and occasionally constitute a significant portion of the fabric (Babel 1975).

The humus form profile commonly ranges from 5 to 20 cm in thickness, with exceptional cases near to, or exceeding 40 cm.

The well developed H horizons of Humimors indicate an intensive rate of synthesis and accumulation of humus materials in the humus form. They may also reflect the maturity of the humus form. They are commonly found under climax coniferous forests in humid and perhumid, temperate, mesothermal and subalpine to boreal climates where humus formation is not influenced by frequently occurring fires.

Key to subgroup

5b1. Humimors which conform to the central concept of the group
Orthihumimor

5b2. Humimors which have a horizon comprised almost entirely of fungal mycelia (designated by "θ" suffix)
Mycohumimor

5b3. Humimors which have >50% by volume of decaying wood within the humus form profile
Lignohumimor

5b4. Humimors which have friable H horizons with a moderate to strong granular structure
Granulohumimor

5b5. Humimors which have Hr >Hd horizons
Residuohumimor

5b6. Humimors which have continuous Ah horizons >2 cm thick in the humus form profile
Amphihumimor

Description of an Orthihumimor

The following description of a humus form profile has the characteristics of the central concept of the Humimors. The profile is located in the Koprino River watershed in the Vancouver Forest Region. The ecosystem is classified as the Tsuga (heterophylla) - Abies (amabilis) - [Picea (sitchensis)] - Vaccinium (alaskaense & parvifolium) - Rhytidiadelphus (loreus) Association on a loamy-skeletal Orthic Ferro-Humic Podzol formed on colluvial veneer over conglomerate bedrock.

Horizon	Depth (cm)	Description
L	18-17	Coniferous needles; moist; non-compact matted; loose; acerose; no visible biota; abrupt wavy boundary.
Fq	17-15	Moist; dark reddish brown (7.5 YR 2/2 m); compact-matted; moderately tenacious; fibrous; plentiful fine to medium roots; few larvae; common yellow mycelia; abrupt, wavy boundary.
Hd	15-0	Moist; very dark gray (10 YR 3/1 m); massive, pliable; greasy; plentiful roots of all sizes; abrupt, wavy boundary.

16. Hydromor

Lafond 1952, Duchaufour 1960 [n.n.; Mader 1953: Swamp Mor; Wilde 1958: Sog Mor; Wilde 1966, 1971: Uliginor; Hartmann 1952: Anaerober Waldnasstorf (in part)]

Characteristic humus form profile:L, Fq, H, [O (Of, Om or Oh)]

Hydromors are poorly aerated Mors which are under the influence of prolonged but not permanent satura-

tion. As a result, O organic horizons may be developed in the lower part of the humus profile; however, Fq and H horizons comprise >50% of the thickness of organic horizons. The associated soils are either Gleysols, gleyed subgroups of other mineral soil orders with well expressed gleying within 50 cm of the mineral surface, or occasionally organic soil. Hydromors are generally <40 cm thick but may occasionally exceed this in exceptional cases. Endorganic horizons are lacking. Hydromors represent a transition between terrestrial and semi-terrestrial humus forms. They were designated as hydromorphic humus forms by Wilde (1958) and Bernier (1968).

Hydromors develop under the direct influence of fluctuating, stagnant or slowly moving water which is generally between 30 and 60 cm below the soil surface. They typically have a thin L horizon (or S layer) on the surface, overlying F and H horizons occupying the upper part of the humus form profile. The F horizon is matted and derived primarily from moss tissues, coniferous litter or residues of hydrophytic vegetation. The H horizons usually have a very weak structure and greasy character. The lower part of the humus form profile may comprise any combination of Of, Om and Oh horizons. These horizons have a massive structure and mushy character. A characteristic feature of Hydromors is that their O horizons have fewer living roots than their F and H horizons.

Hydromors develop in part under hydrolysis and periodic anaerobic fermentation (Wilde 1958). Fungal and minor microfaunal (microarthropods) activities often take place, however, this is generally restricted to the upper horizons which are not subjected to prolonged saturation. Because of this unfavourable edaphic environment, decomposition of organic material is slow, resulting in a build-up of ectorganic horizons.

Hydromors are distributed in boreal, cool mesothermal and temperate climates in physiographic and/or edaphic environments where prolonged saturation of the soils is common.

Key to subgroups (Figure 6)

6a1. Hydromors in which the Hd horizons comprise >70% of the combined thickness of F and H horizons

Orthihydromor

6a2. Hydromors in which the Hr horizons comprise >70% of the combined thickness of F and H horizons

Residuohydromor

6a3. Hydromors in which the H horizons comprise <70% of the combined thickness of F and H horizons

Hemihydromor

6a4. Hydromors in which O horizons comprise between 25 and 50% of the total thickness of organic horizons in the control section

Saprihydromor

Description of an Orthihydromor

The following description of a humus form profile has the characteristics of the central concept of the Hydromor Group. The profile is located in the Koprino River watershed in the Vancouver Forest Region.

The ecosystem is classified as the Tsuga (heterophylla) - Abies (amabilis) - [Picea (sitchensis)] - Vaccinium (alaskaense & parvifolium) - Rhytidiadelphus (loreus)

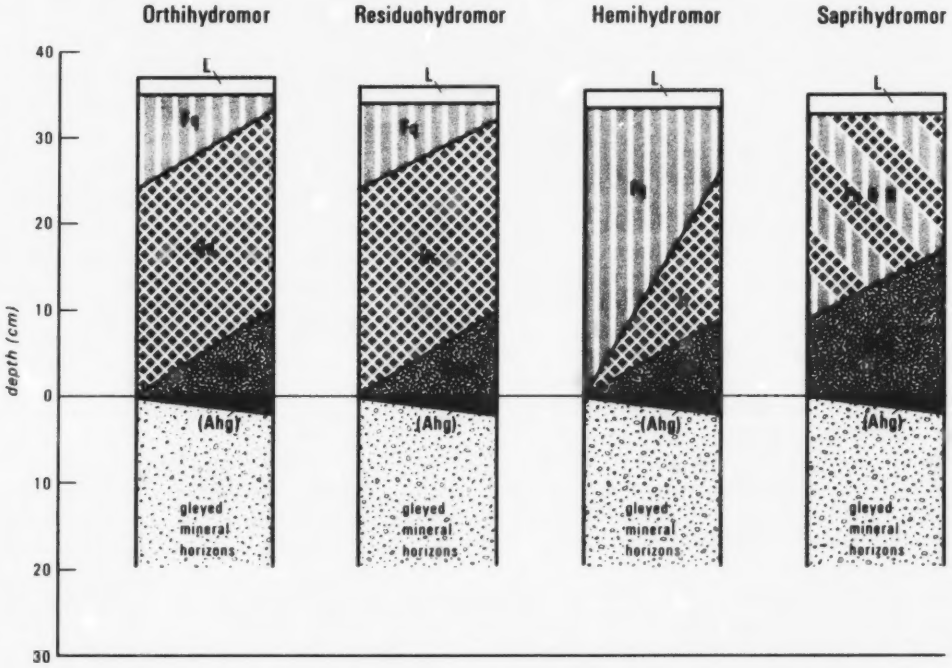

Figure 6. Characteristic humus form profiles of subgroups of the Hydromor group.

Association on a loamy-skeletal Gleyed Ferro-Humic Podzol formed on a morainal blanket over conglomerate bedrock.

Horizon	Depth (cm)	Description
L	36-34	Feather mosses and needles; moist; non-compact matted; loose; acerose; no visible biota; abrupt, smooth boundary.
Fq	34-29	Wet; dark reddish brown (7.5 YR 2/2 m); compact-matted; moderately tenacious; fibrous; plentiful fine to coarse roots; few to common white mycelia; few, medium, clustered decaying wood fragments; abrupt, wavy boundary.
Hd	29-0	Wet; dark reddish brown (5 YR 2.5/2 m); massive; pliable; greasy; common fine to medium roots; no visible biota; common, medium, random decaying wood fragments; abrupt, wavy boundary.

17. Histomor

[n.n.; Kubiena 1953: High Moor; Wilde 1958: Moss Mor (in part); Duchaufour 1960: Peat; Bernier 1968: Fibric Peaty Mor; Hartmann 1952: Abiologischer Sphagnum-Waldnasstorf]

Characteristic humus form profile: S or L, F, H; Of (Om, Oh)

Histomors are very poorly aerated Mors which are under the influence of more or less permanent saturation by dystrophic waters. They are dominated by O horizons, particularly Of, which comprise >50% of the humus form profile. L, F and H horizons may be developed in the upper portion of the profile. Histomors generally exceed 40 cm in thickness. The associated soils are most frequently organic but may occasionally include Gleysols.

Histomors develop under conditions of prolonged saturation due to a stagnant water table, generally located within 30 cm of the ground surface. They typically possess a layer of living mosses (S) mixed with litter materials from vascular plants and typically overlie a thick Of horizon, which is derived primarily from bryophytes, particularly *Sphagnum* mosses, and is always wet and fibrous. Occasionally Om or Oh horizons may occur towards the lower portion of the control section.

Histomors, resulting from a combination of low temperatures, aeration and nutrient content associated with the excessive water supply, are representative of the most inert humus forms. They are distributed in subarctic, boreal, subalpine boreal and cool temperate (marginal) climates in physiographic and/or edaphic environments where a high and permanent water table in the soils is common. Under a perhumid climate, Histomors may occur in organic soils which originated in upland depressions and have subsequently spread over surrounding terrain ("paludification", Heinselman 1963). Histomors generally occur in ecosystems which are sparsely or non-forested.

Key to subgroups (Figure 7)

6b1. Histomors in which the Of horizons comprise >70% of the total thickness of O horizons in the humus form profile

Orthihistomor

6b2. Histomors in which the Of horizons comprise between 50 and 70% of the O horizons in the humus form profile and are underlain by predominantly Om horizons

Fermihistomor

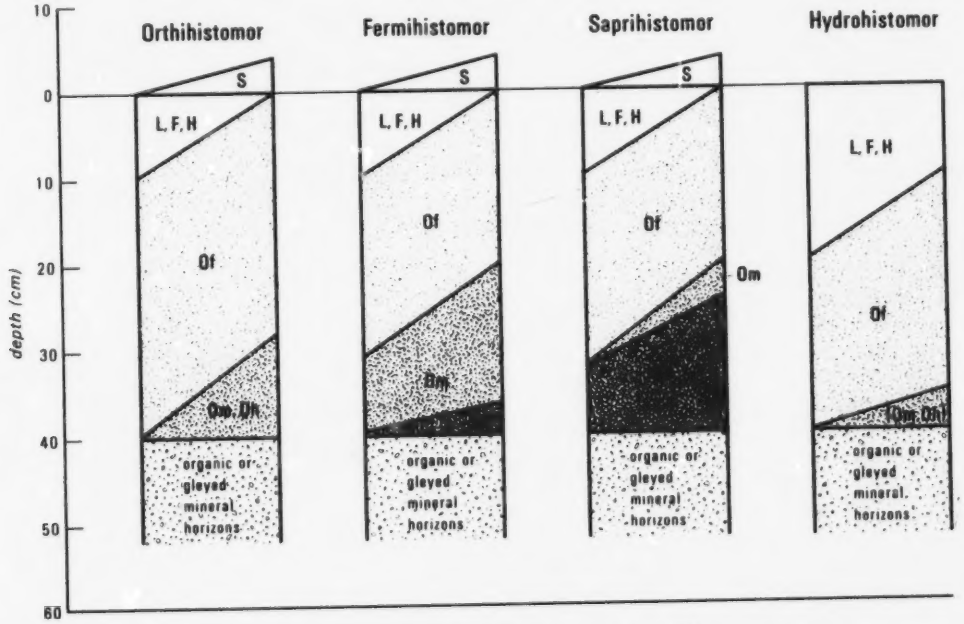

Figure 7. Characteristic humus form profiles of subgroups of the Histomor group.

6b3. Histomors in which Of horizons comprise between 50 and 70% of the O horizons in the humus form profile and are underlain by predominantly Oh horizons

Saprihistomor

6b4. Histomors in which L, F, H horizons comprise between 25 and 50% of the total thickness of organic horizons in the humus form profile

Hydrohistomor

Description of an Orthihistomor

The following description of a humus form profile has the characteristics of the central concept of Histomors. The profile is located adjacent to the North Thompson River in the Kamloops Forest Region. The ecosystem is classified as the Picea (mariana) - Ledum (groenlandicum) - Sphagnum Association on a Typic Mesisol formed on an organic blanket.

Horizon or Layer	Depth (cm)	Description
S	4-0	A layer of living *Sphagnum* mosses.
Of1	0-27	Wet; light brown (7.5 YR 6/4 w); erect; moderately tenacious; mushy; abundant, fine roots; ants and spiders common; gradual, smooth boundary; rubbed fibre approx. 90%.
Of2	27-40+	Wet; reddish brown (5 YR 5/4 w); erect; moderately tenacious; mushy; abundant, fine roots; no visible biota; clear, smooth, boundary; rubbed fibre approx. 80%.

2. Moder Order

Humus forms of the Moder order may be considered transitional between Mors and Mulls. They are similar to Mors in that they generally represent an accumulation of partially to well humified organic materials resting on the mineral soil. On the other hand, they are similar to Mulls in that they are zoologically active (Kubiena 1953, Wilde 1966, Bernier 1968, Babel 1975). Because Moders encompass both of these characteristics, they represent a kind of humus formation distinctly different from either Mors or Mulls. As Wilde put it, Moders (termed "Leptor" in his classification) are "the most biologically active forms of ectohumus".

Terrestrial Moders are characterized by the diagnostic Fa horizon. This horizon is comprised primarily of partly decomposed plant residues which have been fragmented or comminuted by soil fauna and which are loosely arranged, not matted as in the Fq horizons (Kubiena 1953, Bernier 1968). Occasionally an abundance of fine roots may create a matted appearance (Armson 1977). In addition to the loose consistency, a characteristic feature of the Fa horizon is the numerous soil fauna droppings which are readily observable under magnification. These droppings originate from many types of fauna, including centipedes, millipedes, collembola, mites, isopods and various insect larvae. Fragmentation of plant residues by soil fauna promote an increased rate of decomposition. Although fungi still play an important role, increasing numbers of bacteria, actinomycetes, and protozoa contribute to the decomposition process.

In the Mormoder group, the F horizon takes on characteristics of both Fa and Fq horizons (thus designated as Faq). Fungal mycelia may be fairly common and plant residues may appear somewhat matted, however, many small insect droppings can still be observed.

Hd horizons are found in most Moder humus forms. They are often permeated by loose, incoherent mineral particles (Kubiena 1953, Bernier 1968, Babel 1975). Such horizons are designated by the lowercase suffix " ι ". However, this feature is not considered diagnostic of Moders since Mor humus forms may possess similar horizons. Babel's (1975) observations of humus form micromorphology indicated that H horizons have no clear, distinguishing features which would indicate whether they are from Mors or Moders.

Moder humus forms may be comprised of ectorganic horizons only or ectorganic horizons underlain by endorganic horizons. This horizon contains fine humus materials which have infiltrated into the mineral soil. Although organic matter may be transported into the upper portion of this horizon by soil fauna, this will only occur over a very short distance (Babel 1975). The upper boundary of the Ah horizon is generally gradual, in contrast to the abrupt transition typical of similar situations in the Mor humus forms.

In comparison to Mors, in general, chemical properties of Moders show lower acidity, total carbon, carbon: nitrogen ratio, and cation exchange capacity, and higher total nitrogen and base saturation. This suggests that Moders provide more available nutrients than Mors.

Moders develop under the influence of semiarid, temperate and mesothermal climates, particularly under forest stands which yield easily decomposable litter, generally from deciduous overstory or understory vegetation. Mormoder and Mullmoder, the intergrade groups of the Moder order, may be found under less favourable and more favourable "hydrothermal"[1] conditions, respectively.

The Moder order is subdivided into seven groups based on soil moisture regime, and kind and arrangement of horizons (Table 9, Figure 8).

TABLE 9. *Synopsis of Taxa of the Moder Order*

Group	Subgroup
21. Velomoder	211. Orthivelomoder 212. Minerovelomoder 213. Amphivelomoder
22. Xeromoder	221. Orthixeromoder 222. Mineroxeromoder 223. Amphixeromoder
23. Mormoder	231. Orthimormoder 232. Humimormoder 233. Mineromormoder 234. Amphimormoder
24. Leptomoder	241. Orthileptomoder 242. Hemileptomoder

[1]Hydrothermal - combination of temperature and moisture regimes (Kononova 1961).

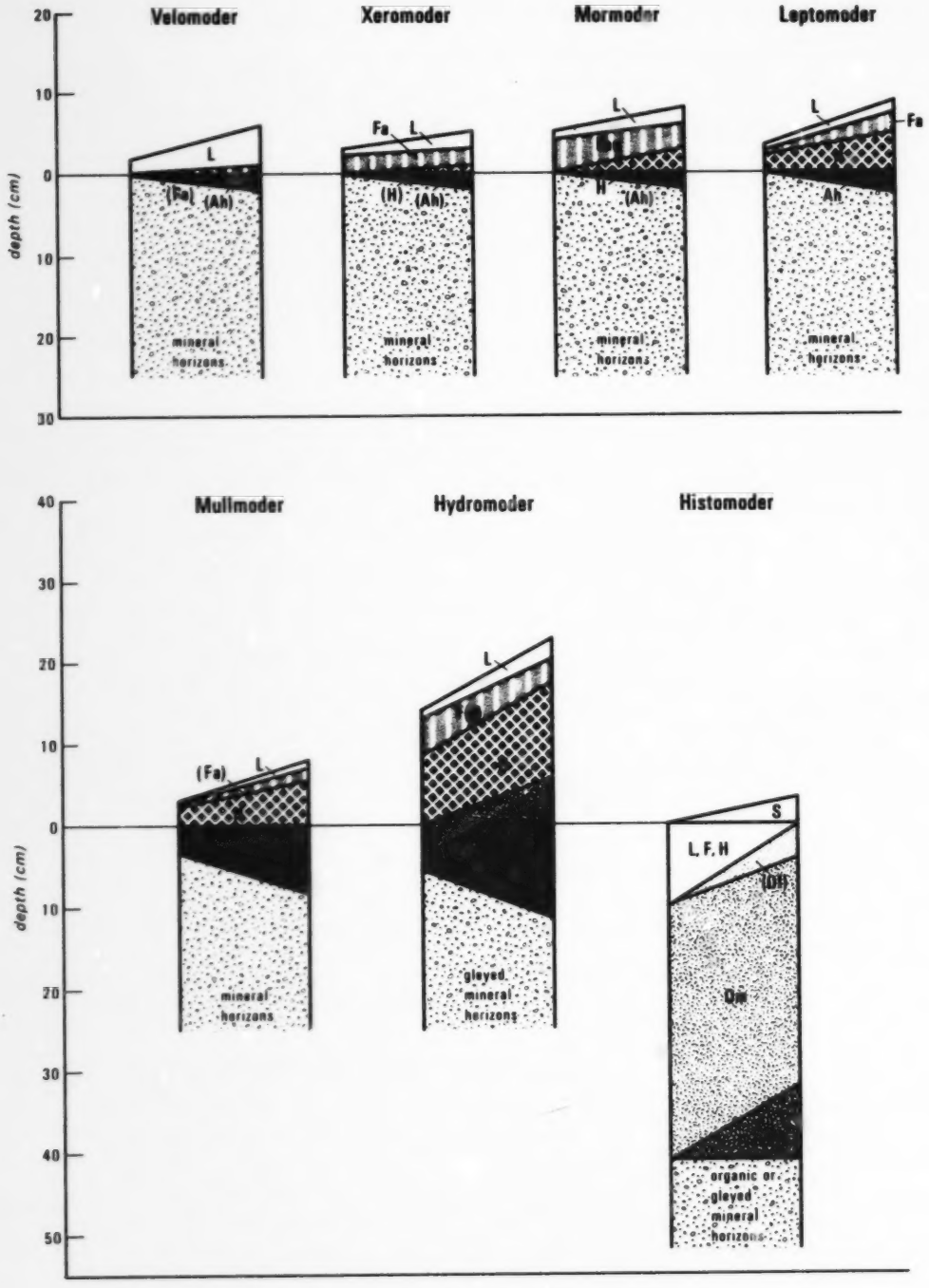

Figure 8. Characteristic humus form profiles of groups of the Moder order represented by *orthi* subgroups.

TABLE 9. *Synopsis of Taxa of the Moder Order* - Continued

Group	Subgroup
	243. Mineroleptomoder
	244. Amphileptomoder
25. Mullmoder	251. Orthimullmoder
	252. Vermimullmoder
	253. Rhizomullmoder
26. Hydromoder	261. Orthihydromoder
	262. Ectohydromoder
	263. Saprihydromoder
27. Histomoder	271. Orthihistomoder
	272. Fibrihistomoder
	273. Saprihistomoder
	274. Hydrohistomoder

Key to Groups of the Moder Order

1a. Well aerated Moders; can be temporarily saturated by water

2a. L horizons comprise >80% of the total thickness of ectorganic horizons. Thin Fa horizons are always present

Velomoder

2b. L horizons comprise < 80% of the total thickness of ectorganic horizons. Fa or Faq horizons always present

3a. Prolonged moisture deficiency during the growing season (xeric moisture regimes)

Xeromoder

3b. None or short term moisture deficiencies

4a. Fa horizons present in humus form profile

5a. Total thickness of endorganic horizons > total thickness of ectorganic horizons (excluding L)

Mullmoder

5b. Total thickness of endorganic horizons < total thickness of ectorganic horizons (excluding L)

Leptomoder

4b. Faq horizons present in humus form profile; Fa horizons minor or absent

Mormoder

1b. Poorly aerated Moders, prolonged or permanent saturation by water (hygric to subhygric moisture regimes)

6a. F horizons and/or H horizons comprise >50% of the thickness of organic horizons in the humus form profile. Ah or Ahg horizons >5 cm thick present

Hydromoder

6b. (Of), Om (and Oh) horizons comprise >50% of the thickness of organic horizons in the humus form profile. The Om horizons comprise >50% of the combined thickness of these O horizons

Histomoder

21. Velomoder

[n.n; Kubiena 1953: Raw Soil Humus (in part); Wilde 1958: Velum (in part); Wilde 1966, 1971: Velor (in part)]

Characteristic humus form profile: L, (Fa), (Ah)

Velomoders consist essentially of an accumulation of litter materials, usually coniferous foliage, underlain by very thin Fa horizons. Specifically, L horizons comprise >80% of the thickness of the ectorganic horizons. They have single particle structure, loose consistency and acerose character. They are generally under 10 cm in thickness.

These humus forms are considered to represent the early stages of development, either primary or secondary, of Moders. They show a lack of humus materials, which, in forested ecosystems, may be attributed to a high amount of litterfall and the climatic environment in young, dense coniferous stands. As these stands mature and openings in the canopy occur, the rate of decomposition is increased with F horizons becoming more prominent and H horizons appearing. Velomoders may also be associated with some climax stands which experience periodic destruction of humus horizons through underburning.

Key to subgroups

2a1. Velomoders that conform to the central concept of the group

Orthivelomoder

2a2. Velomoders which contain significant amounts of mineral particles intermixed throughout the humus form profile, as indicated by Lt and Fat horizons

Minerovelomoder

2a3. Velomoders that have a continuous Ah horizon >2 cm thick in the humus form profile

Amphivelomoder

Description of an Orthivelomoder

The following description of a humus form profile has the characteristics of the central concept of Velomoders. The profile is located near Campbell Lake in the Vancouver Forest Region. The ecosystem is classified as the immature variant of the Thuja (plicata) - Pseudotsuga (menziesii) - Mahonia (nervosa) - Polystichum (munitum) Association on a loamy Orthic Humo-Ferric Podzol formed on morainal materials overlying volcanic bedrock.

Horizon	Depth (cm)	Description
L	3.0-0.5	Douglas-fir needles; moist; single particle (non-compact matted in lower portion); loose; acerose; no roots; no visible biota; abrupt, smooth boundary.
Fa	0.5-0	Moist; weak, non-compact matted; loose to friable; acerose; no roots; common, fine droppings, common insects (wood-lice, nematodes, centipedes), mycelia lacking; abrupt, smooth boundary.
(Hd)	discontinuous	Incipient horizon forming in small pockets.

22. Xeromoder

(n.n.; Duchaufour 1960: Xeromorphic Moder)

Characteristic humus form profile: L, Fa, (H), (Ah)

Xeromoders are well aerated Moders that are influenced by prolonged moisture deficiencies during the growing season, resulting primarily from climatic and/or edaphic limitations. As limited data is available, the following characteristics of Xeromoders are tentative and subject to further study.

The humus form profile typically has thin L horizons derived primarily from coniferous needles, lichen and bryophyte tissues and residues of herbaceous (graminoid) plants. The underlying Fa horizon is comprised of a loose to weakly consolidated accumulation of partially decomposed plant residues, not matted as in Xeromors. Fungal mycelia are of minor significance. If present, they are generally very fine and scattered in isolated pockets. Bryophyte rhizoids may be abundant, creating a fibrous character. Unlike Leptomoders, faunal droppings are not readily observable in the F horizon. Because of moisture limitations, the fauna which are most active include mites, collembola and other tiny microfauna. These species generally produce very small (less than approx. 0.1 mm) droppings which are difficult to observe (Hodgson 1978). Scattered droppings of larger fauna may occasionally be found.

H horizons are generally thin or lacking entirely. Where present, they are often permeated with loose mineral grains. All horizons are typically dry or desiccated during much of the growing season, except for relatively short durations following precipitation.

Decomposition and humification of organic matter tend to be suppressed in Xeromoders as a result of moisture deficiencies. F horizons, therefore, tend to be dominant in many profiles. Biological activity is greatest during periods of favourable hydrothermal conditions, usually in the early growing season. Ecosystems supporting Xeromoders may experience a history of repeated underburns. This repeated destruction of the humus impedes the build up of organic horizons, particularly the H. In addition, litter production is often sparse on these sites resulting from low ecosystem productivity.

Xeromoders are frequently found in ecosystems in semiarid climates or on edaphically dry sites in temperate, subhumid and humid climates. Forest stands are generally open or lacking entirely.

Key to subgroups

3a1. Xeromoders that conform to the central concept of the group

Orthixeromoder

3a2. Xeromoders which contain significant amounts of mineral particles intermixed throughout the humus profile, as indicated by Fa$_t$ and H$_t$ horizons

Mineroxeromoder

3a3. Xeromoders that have a continuous Ah horizon >2 cm thick in the humus form profile

Amphixeromoder

Description of an Orthixeromoder

The following description of a humus form profile has the characteristics of the central concept of Xeromoders. The profile is located near Kamloops in the Kamloops Forest Region. The ecosystem is classified as the Pinus (ponderosa) - Agropyron (spicatum) Association on a sandy Orthic Eutric Brunisol formed on fluvial materials over volcanic bedrock.

Horizon	Depth (cm)	Description
L	3-2	Ponderosa pine needles; dry; single particle; acerose; loose; no roots; no visible biota; abrupt, smooth boundary.
Fa	2-0.2	Dry; weak non-compact matted; loose; acerose; very few, fine roots; few, medium droppings, abundant, white mite eggs, and microcentipedes commonly observed; few, small clusters of very fine, felty mycelia; abrupt, smooth boundary.
Hd$_t$	0.2-0	Dry; weak, fine granular; gritty; very friable; few fine roots; common quartz grains; no visible biota; clear, smooth boundary.

23. Mormoder

[n.n.; Kubiena 1953: Coarse Moder; Wilde 1966: Velor (in part); Bernier 1968: Raw Moder; Hartmann 1952: Eumycetischer Moder (Pilzmoder)]

Characteristic humus form profile: L, Faq, H, (Ah)

Mormoders are well aerated Moders which are transitional to Mor humus forms. They are characterized by the Faq horizons present in the humus form profile. This Faq horizon generally has characteristics of both Mors and Moders in that both soil animals and fungi may be active. Some of the following characteristics are tentative due to a lack of data.

The Faq horizon is comprised of partially decomposed needles and leaves arranged into a weak to moderate, compact or non-compact matted structure. The materials are seldom as strongly matted as in true Mors. Fungal mycelia are generally present but are seldom abundant. Insect droppings are observable in most cases, although they are usually smaller and less common than in Leptomoders.

H horizons are generally thin, but they occasionally comprise > 50% of the profile (excluding L). Their structure is fine to medium granular and may contain a significant proportion of insect droppings. The H is often permeated by loose mineral grains.

Mormoders are morphologically similar to Hemimors or Hemihumimors. They are most frequently under 10 cm in total thickness. The dominant Faq horizon indicates that the rates of decomposition are somewhat less than the zoologically more active Leptomoders. In comparison to sites commonly supporting Leptomoders, Mormoders tend to develop on drier habitats in ecosystems yielding less easily decomposed litter. They are frequently found under coniferous ecosystems influenced by subhumid to humid, temperate to mesothermal climates.

Key to subgroups

4b1. Mormoders that conform to the central concept of the group

Orthimormoder

4b2. Mormoders in which the Faq horizons comprise < 50% of the combined thickness of the F and H horizons

Humimormoder

4b3. Mormoders which contain significant amounts of mineral particles intermixed throughout the humus profile, as indicated by Faq$_i$ and H$_i$ horizons

Mineromormoder

4b4. Mormoders that have a continuous Ah horizon > 2 cm thick in the humus form profile

Amphimormoder

Description of an Orthimormoder

The following description of a humus form profile has the characteristics of the central concept of Mormoders. The profile is located near Sayward in the Vancouver Forest Region. The ecosystem is classified as the Thuja (plicata) - Pseudotsuga (menziesii) - Polystichum (munitum) - Mahonia (nervosa) on a loamy Orthic Humo-Ferric Podzol formed on colluvial materials overlying volcanic bedrock.

Horizon	Depth (cm)	Description
L	5-4	Douglas-fir needles; moist; single particle to non-compact matted in lower portion; loose; acerose; no roots; no visible biota; abrupt, smooth boundary.
Faq	4-1.5	Moist; weak, compact matted; friable to very weakly tenacious; slightly felty; few, fine roots; common, coarse white "flecks" and common fine, felty, brown mycelia, clusters of medium and coarse droppings, few to common insects (nematodes, woodlice, spiders); abrupt, smooth boundary.
Hd	1.5-0	Moist; weak, medium, granular; very friable; greasy; common, fine roots; common, coarse white "flecks" of mycelia in upper portion; abrupt, wavy boundary.

24. Leptomoder

[n.n.; Hoover and Lunt 1952: Duff Mull (in part); Kubiena 1953: Moder; Wilde 1958: Duff Mull (in part); Wilde 1966, 1971: Leptor; Bernier 1968: Typical Moder; Hartmann 1952: Arthropodenmoder (Insektenmoder)].

Characteristic humus form profile: L, Fa, H, (Ah)

Leptomoders are well aerated Moders which have a distinct Fa horizon underlain by an H horizon that may or may not contain intermixed mineral grains. Specifically, Leptomoders have distinct Hd$_i$ or Hd horizons overlain by Fa horizons. The total thickness of ectorganic horizons (excluding L horizons) exceeds the total thickness of endorganic horizons, if present.

The Fa horizon is comprised of partially decomposed plant residues which have been comminuted by soil fauna. These materials are typically arranged into a loose to weak, non-compact matted structure. Occasionally a matted appearance prevails due to an abundance of fine roots. Many faunal droppings are readily observable, particularly under magnification. Fungal mycelia are either absent or are present in minor amounts. The Fa horizons are typically thin, seldom exceeding 3 cm. H horizons are better developed than the Fa horizons. They are often permeated by loose mineral grains and may contain a significant proportion of droppings, occasionally constituting the entire fabric. The ectorganic horizons commonly range from 5 to 15 cm in total thickness.

Leptomoders represent humus forms that contain active populations of arthropods and other fauna, which promote "far-going but not complete humification" (Kubiena 1953) of organic residues. They develop in response to favourable conditions of moisture, temperature and aeration, commonly under stands which yield easily decomposable litter (i.e. deciduous overstory and understory species).

Key to subgroups

5b1. Leptomoders which conform to the central concept of the group

Orthileptomoder

5b2. Leptomoders in which the thickness of the Fa is ≥ the H horizon

Hemileptomoder

5b3. Leptomoders which contain significant amounts of mineral particles intermixed throughout the humus form profile, as indicated by Fa$_i$ and H$_i$ horizons

Mineroleptomoder

5b4. Leptomoders that have continuous Ah horizons > 2 cm thick in the humus form profile

Amphileptomoder

Description of an Orthileptomoder

The following description of a humus form profile has the characteristics of the central concept of Leptomoders. The profile is located near Sayward in the Vancouver Forest Region. The ecosystem is classified as the Thuja (plicata) - Pseudotsuga (menziesii) - Polystichum (munitum) - Tiarella (trifoliata) Association on a loamy Orthic Humo-Ferric Podzol formed on a morainal blanket.

Horizon	Depth (cm)	Description
L	6.5-6.0	Douglas-fir needles and *Polystichum* foliage; moist; single particle; loose; acerose; no roots; few clusters of fine and medium droppings; abrupt, smooth boundary.
Fa	6.0-4.5	Moist; non-compact matted; loose; (soft) acerose; no roots; common, fine and medium droppings in clusters, few, aggregated worm casts, common insects (woodlice, centipedes, spiders, nematodes, large larvae); few, scattered clusters of very fine, felty mycelia; abrupt, smooth boundary.
Hd	4.5-1	Moist; fine granular; friable; greasy; common, fine roots; few, medium, clusters of charcoal; abundant, medium droppings; mycelia lacking; abrupt, smooth boundary.
Hdα	1-0	Moist; fine granular; friable; gritty; common, fine roots; common, medium droppings; mycelia lacking; abrupt, wavy boundary.

25. Mullmoder

[n.n. Kubiena 1953: Mull-like Moder (in part); Wilde 1958: Microbiotic Mull (in part); Wilde 1966, 1971: Parvital (in part); Bernier 1968: Mull-like Moder (in part); Hartmann 1952: Saurer Waldmull]

Characteristic humus for profile: (L), (Fa), H, Ah

Mullmoders are well-aerated Moders which are transitional to Mull humus forms. They differ from Mulls in that they have H horizons greater than 1 cm thick. Specifically, Mullmoders have Ah horizons greater than 2 cm thick, overlain by Fa and H horizons whose combined thickness is less than the total thickness of the endorganic horizons.

Hd horizons containing significant amounts of intermixed mineral grains are usually present. Soil fauna, including arthropods, nematodes, and occasionally earthworms, are generally active in these humus forms, contributing to the intermixing of mineral grains. Where this activity results in Hd horizons containing clearly identifiable insect droppings, the designation Hda or Hdaα may be used. The fabric of the H horizons is typically very fine or medium granular with a greasy or gritty character and high porosity.

Mullmoders undergo relatively rapid decomposition of organic residues. However, decomposition and intermixing promoted by large soil fauna such as earthworms is not extensive enough for complete incorporation of humus materials with the uppermost mineral horizons, as in Mulls. Mullmoders may be associated with internal input and decomposition of finely divided root systems, in which case the Rhizomullmoder is recognized.

Mullmoders are distributed most frequently in mesothermal, temperate and occasionally boreal climates in ecosystems providing favourable moisture and nutrient supply for soil fauna and microflora, and yielding easily decomposable litter.

Key to subgroups

3b1. Mullmoders which conform to the central concept of the group
Orthimullmoder

3b2. Mullmoders in which earthworms are active in the humus form profile
Vermimullmoder

3b3. Mullmoders that have a dense network of finely divided roots. The Ah horizon is rhizogenous
Rhizomullmoder

Description of an Orthimullmoder

The following description of a humus form profile has the characteristics of the central concept of Mullmoders. The profile is located near Campbell River in the Vancouver Forest Region. The ecosystem is classified as the Thuja (plicata) and Abies (grandis) - Pseudotsuga (menziesii) - Polystichum (munitum) - Tiarella (trifoliata) on a sandy Gleyed Dystric Brunisol formed on fluvial materials.

Horizon	Depth (cm)	Description
Lv	5.0-4.5	Coniferous needles, herbaceous and deciduous leaves; moist; single particle; loose; leafy; no roots; abundant springtails, few fine droppings; abrupt, smooth boundary.
Fa	4.5-4.0	Moist; single particle; loose; no roots; abundant springtails; common millipedes, abundant aggregates of droppings; abrupt, smooth boundary.
Hdaα	4.0-0	Moist; moderate, very fine, granular; very friable; gritty; common, fine roots; common millipedes; abundant droppings dominating the fabric; clear, wavy boundary.
Ah	0-6	Moist; moderate, medium, granular; friable; silt loam; abundant, medium roots; few earthworms and casts; clear, smooth boundary.

26. Hydromoder

Duchaufour 1960 [n.n.; Wilde 1966, 1971: Uliginorm (in part)]

Characteristic humus form profile: L, F(a), H, (Oh), Ah(g)

Hydromoders are poorly aerated Moders which are under the influence of prolonged but not permanent saturation. They have L, F and H horizons which comprise >50% of the total thickness of organic horizons in the humus form profile. As a result of prolonged saturation, O horizons (primarily Oh) may be developed in the lower portion of the profile. Ah horizons >5 cm thick are usually present in the control section. If they are lacking, the H horizons must contain intermixed mineral materials. Associated soils are either Gleysols, gleyed subgroups of other mineral soil orders with well expressed gleying within 50 cm of the mineral surface, or occasionally organic soils. Hydromoders represent a transition

between terrestrial and semi-terrestrial humus forms and have been designated as hydromorphic by Wilde (1958) and Bernier (1968).

Hydromoders develop under direct influence of fluctuating or slowly moving water which is generally located between 30 and 50 cm from the soil surface. They typically have thin L horizons on the surface, overlaying F horizons derived primarily from coniferous litter, bryophyte tissues and residues of hydrophytic vegetation. Their structure is usually non-compact or compact matted.

Soil fauna are active in the upper portion of the horizons which is not subject to prolonged saturation. Fungal mycelia are generally present in minor amounts.

The H horizons generally have weak or massive structure and are greasy in character. They often contain significant amounts of intermixed mineral material, usually from siltation and sedimentation.

Ah horizons are typically friable with weak granular or blocky structure, occasionally showing evidence of gleying. Ectorganic horizons of Hydromoders average from 10 to 20 cm in total thickness while endorganic horizons are generally in the 15 to 30 cm range.

Hydromoders develop in part under hydrolysis and periodic anaerobic fermentation (Wilde 1958). Decomposition by soil fauna and fungi is generally restricted to the upper horizons which are not subjected to prolonged saturation. Hydromoders generally develop under less acid conditions than Hydromors. Chemical properties of Hydromoders show higher levels of exchangeable bases and base saturation, and lower C/N values than Hydromors, indicating more favourable nutrient regimes for plant growth.

Hydromoders are distributed in temperate, mesothermal and boreal climates, in physiographic and/or edaphic environments where prolonged saturation of the soil is common. Base-rich soil parent materials are often associated.

Key to subgroups (Figure 9)

6a1. Hydromoders that conform to the central concept of the Group. Oh horizons comprising < 25% of the thickness of organic horizons may be present
Orthihydromoder

6a2. Hydromoders in which Ah horizons are either absent or < 5 cm thick. H horizons > 5 cm thick are always present
Ectohydromoder

6a3. Hydromoders in which Oh horizons comprise from 25-50% of the total thickness of organic horizons. If Oh$_t$ horizons >5 cm thick are present, Ahg horizons may be lacking; otherwise, Ahg horizons > 5 cm thick must be present
Saprihydromoder

Description of an Orthihydromoder

The following description of a humus form profile has the characteristics of the central concept of Hydromoders. The profile is located near the Nechako River in the Prince Rupert Forest Region. The ecosystem is classified as the Picea (glauca) - Ribes (lacustre) - Aulocommium (palustre) Association on a clayey Rego Humic Gleysol formed on a lacustrine veneer.

Horizon	Depth (cm)	Description
L	11-10	Coniferous needles; moss tissues; moist; single particle; loose; acerose; no roots; no visible biota; clear, smooth boundary.
F(a)	10-4	Moist; non-compact matted; slightly tenacious; fibrous; few, fine roots, common in-

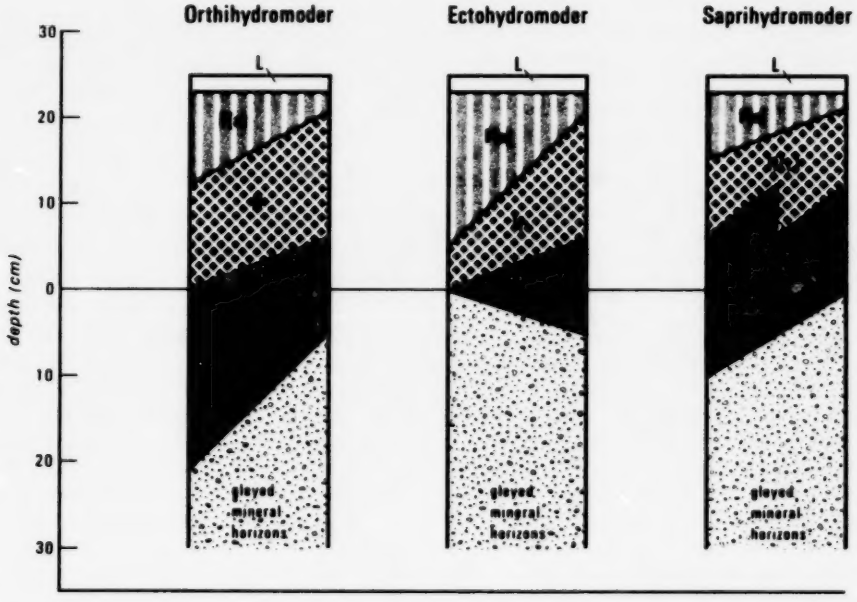

Figure 9. Characteristic humus form profiles of subgroups of the Hydromoder group.

		sects in upper portion; few, white mycelia; clear, smooth boundary.
Hd	4-0	Moist; black (10 YR 2/1 m); weak compact matted; moderately tenacious; greasy; plentiful, fine and medium roots; no visible biota; clear, smooth boundary.
Ah	0-15	Wet; black (10 YR 2/1 m); weak, fine, subangular blocky; friable; clay; few, medium roots; no visible biota; clear, smooth boundary.

27. Histomoder

[n.n.; Bernier 1968: Mesic Peaty Mor]

Characteristic humus form profile: S or L, F, H; (Of), Om, (Oh)

Histomoders are very poorly aerated Moders which are under the influence of permanent saturation. They are dominated by wetland (O) organic horizons, in particular Om, which comprises >50% of the humus form profile. L, F, and H horizons may occasionally be developed in the upper portion of the profile. Associated soils are most frequently Organic, but may include Gleysols.

Histomoders form in environments of prolonged saturation resulting from a slow moving subsurface water flow or a stagnant water table, generally located within 30 cm of the ground surface. They typically possess a thin layer of living mosses (S) mixed with litter materials from vascular plants, overlying thick Om horizons. These are derived primarily from tissues of bryophytes and sedges, and are always wet. Thin Of horizons may be found in the upper profile. Occasionally Oh horizons occur towards the lower portion of the control section.

Histomoders represent humus forms in which decomposition and synthesis of organic materials is suppressed due to low temperatures and low aeration brought on by saturated conditions. However, decomposition has reached a moderately advanced state, primarily as a result of greater levels of nutrients in the water. Histomoders may be considered as semi-terrestrial humus forms intermediate between the relatively undecomposed Histomors and the well humified Saprimulls. They are distributed in mesothermal, temperate or boreal climates in physiographic and/or edaphic environments where a high and permanent water table is common in the soils. Groundwater in the ecosystems is generally weakly acid.

Key to subgroups (Figure 10)

6b1. Histomoders in which the Om horizons comprise >70% of the total thickness of O horizons in the humus form profile
Orthihistomoder

6b2. Histomoders in which the Om horizons comprise between 50 and 70% of the O horizons in the profile and are overlain by Of horizons
Fibrihistomoder

6b3. Histomoders in which the Om horizons comprise between 50 and 70% of the O horizons in the profile and are underlain by Oh horizons
Saprihistomoder

6b4. Histomoders in which L, F and H horizons comprise between 25 and 50% of the total thickness of organic horizons in the humus form profile
Hydrohistomoder

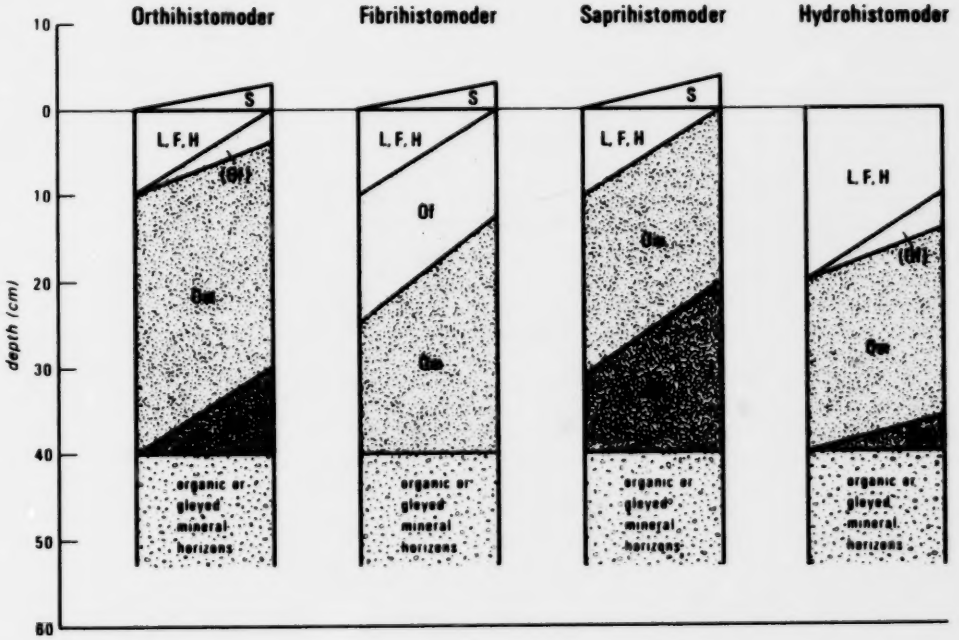

Figure 10. Characteristic humus form profiles of subgroups of the Histomoder group.

Description of an Orthihistomoder

The following description of a humus form profile has the characteristics of the central concept of Histomoders. The profile is located near Williams Lake in the Cariboo Forest Region. The ecosystem is classified as the Betula (glandulosa) - Carex (rostrata & aquatilis) - Tomenthypnum (nitens) Association on a Typic Mesisol formed on an organic blanket.

Horizon	Depth (cm)	Description
S	3-0	Layer of living mosses.
Om	0-40	Saturated; reddish-brown (5 YR 5/4 m); massive; tenacious; mushy; plentiful, fine and medium roots; no visible biota; gradual, irregular boundary; rubbed fibre approximately 30%; von Post class 5.

3. Mull Order

The Mull order encompasses humus forms in which organic matter is intimately incorporated into the upper mineral soil instead of accumulating on its surface as in Mors and Moders. Decomposition of organic materials and formation of humus substances takes place rapidly in comparison to the Mor and Moder orders. Under a subhydric moisture regime, humification also proceeds relatively rapidly. However, in these cases, intermixing with mineral soil does not necessarily take place. Because of the predominance of well humified materials, the semi-terrestrial Mulls are considered to belong to the Mull Order. This contrasts with semi-terrestrial Mors and Moders in which moderate to poorly decomposed organic residues predominate over humified materials.

Mull humus forms are characterized by Ah horizons or in Saprimulls by Oh horizons. These are generally overlain by thin L horizons and occasionally Fa horizons which do not exceed 1 cm in thickness. The Ah horizons contain organic matter which has been incorporated into the mineral soil either by active burrowing and comminution by soil fauna, particularly earthworms, or by partial decomposition of finely divided root systems of herbaceous (graminoid) plants. In some hydromorphic Mulls, the intermixing of organic matter and mineral soil may result from inwashing of mineral sediments. The Ah horizons of Mulls typically have granular or occasionally (subangular) blocky structure. The lower boundary generally merges gradually into the underlying mineral horizon.

Rapid decomposition and humification of organic materials in Mulls is promoted by active populations of soil fauna and abundant colonies of bacteria (Waksman 1938). Habitat conditions which promote this activity include good aeration, balanced moisture supply, nutrient-rich soils or seepage water effects, favourable temperatures and a supply of easily decomposable litter. Chemical properties indicate that Mull humus forms typically have significantly higher values of pH and base saturation, and lower C/N ratios relative to Moder and Mor humus forms. In comparison to the other orders, Mulls may be considered as providing the greatest amount of available nutrients to plants, in particular, nitrogen.

Mulls develop under the influence of a relatively wide range of temperate, semiarid, mesothermal, subtropical and tropical climates. They are generally found in ecosystems developed on base-rich soil parent materials, which may be influenced by minerotrophic seepage waters. Subtropical and tropical Mulls (Wilde 1971) were not included in the taxonomy.

The Mull order is subdivided into four groups based on soil moisture regime, and kind and arrangement of horizons (Table 10, Figure 11).

TABLE 10. *Synopsis of Taxa of the Mull Order*

Group	Subgroup
31. Rhizomull	311. Orthirhizomull 312. Crustorhizomull 313. Vermirhizomull 314. Xerorhizomull
32. Vermimull	321. Orthivermimull 322. Microvermimull 323. Macrovermimull
33. Hydromull	331. Orthihydromull 332. Humihydromull 333. Saprihydromull
34. Saprimull	341. Orthisaprimull 342. Parasaprimull 343. Histosaprimull 344. Humisaprimull 345. Hydrosaprimull

Key to Groups of the Mull Order

1a. Well aerated Mulls which can be temporarily saturated by water; Ah horizons >2 cm thick always present; F horizons < 1 cm thick

2a. Rhizogenous Ah horizons developed from decomposition of dense network of fine roots of herbaceous vegetation, creating a sod[1]; structure is generally blocky

Rhizomull

2b. Zoogenous Ah horizons developed primarily by active populations of earthworms. Structure is always granular

Vermimull

1b. Poorly aerated Mulls; prolonged or permanent saturation by water (hygric to subhydric moisture regimes)

3a. Humus form profile dominated by Ah(g) horizons; F horizons always < 1 cm thick. Oh horizons, if present, are less than the thickness of the Ah(g)

Hydromull

3b. Humus form profile dominated by Oh horizons; the combined thickness of F, Of, Om and Ah horizons is always less than the thickness of the Oh horizons

Saprimull

[1]Sod - (turf, sward) stratum of soil filled with roots of grass, herbs, etc. (Webster 1959).

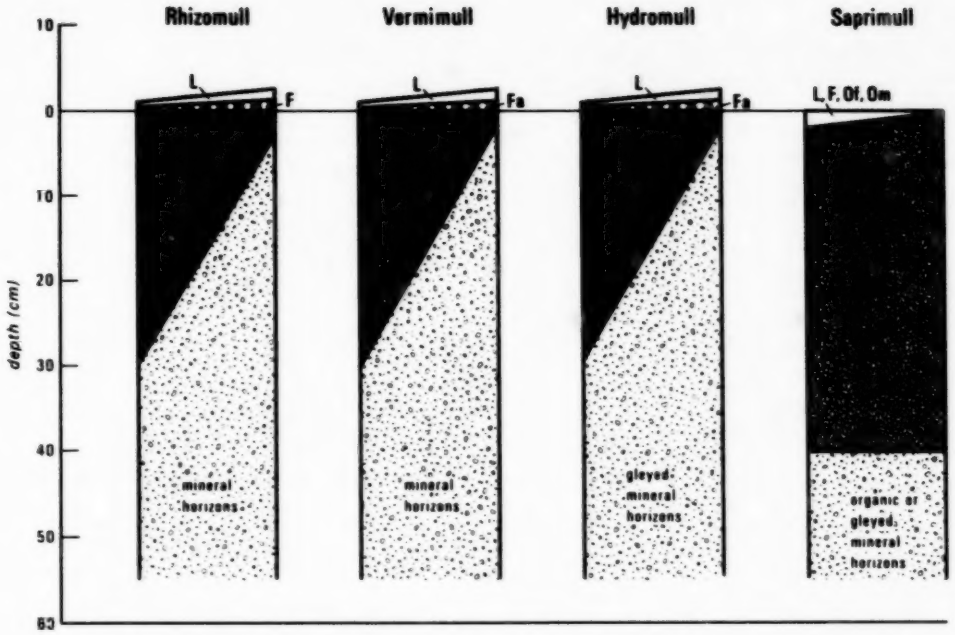

Figure 11. Characteristic humus form profiles of groups of the Mull order represented by *orthi* subgroups.

31. Rhizomull

[n.n.; Wilde 1958: Sward; Barratt 1964: Grassland Mull; Wilde 1966, 1971: Rhizol; Hartmann 1952: Kalkreicher Mull (Kalkmull) (in part), Salzreicher Mull (Salzmull) (in part)]

Characteristic humus form profile: (L), (F), Ah

Rhizomulls are well aerated Mulls in which the Ah horizons are formed through the decomposition of finely divided root systems of herbaceous (primarily graminoid) plants. They typically possess thin, occasionally discontinuous L horizons overlaying the Ah horizons. F horizons may be present, however, they are always very thin because of low levels of above-ground litter production. H horizons are generally lacking.

The typically dark coloured Ah horizon is characterized by subangular blocky or occasionally granular structure. A dense network of fine roots is always present creating a "sward" or "turf". Earthworms are generally absent, but where the humus form develops on moist soils influenced by groundwater, they may become more significant. The humus form profile averages 10 to 15 cm in thickness but may extend over 25 cm in extreme cases.

Rhizomulls develop most commonly in subhumid to semiarid climates under an extensive cover of perennial grasses. Associated soils are typically rich in bases. They may also form under moister and cooler climates, providing the site supports a well-developed community of herbaceous vegetation producing dense root networks.

Key to subgroups

2a1. Rhizomulls which conform to the central concept of the group
Orthirhizomull

2a2. Rhizomulls that have brittle and firm, crust-like horizons in the upper portion of the humus form profile
Crustorhizomull

2a3. Rhizomulls in which earthworms are common; structure of the Ah horizons is generally granular
Vermirhizomull

2a4. Rhizomulls which experience prolonged moisture deficiencies during the growing season (i.e. semiarid climates; xeric (to submesic) moisture regimes in subhumid climates)
Xerorhizomull

Description of an Orthirhizomull

The following description of a humus form profile has the characteristics of the central concept of Rhizomulls. The profile is located near Princeton in the Kamloops Forest Region. The ecosystem is classified as the Eriogonum (heracleoides) - Festuca (idahoensis) Association on a loamy Orthic Black Chernozem formed on morainal materials over volcanic bedrock.

Horizon	Depth (cm)	Description
L	0.3-0	Leaves and stems of graminoid plants; dry; single particle; acerose; loose; no roots; no visible biota; abrupt, broken boundary.
Ah	0-10	Moist; black (10 YR 2/1 m) to very dark gray (10 YR 3/1 d); moderate, medium granular; friable; sandy loam; abundant fine roots; no visible biota; gradual, smooth boundary.

32. Vermimull

[n.n.; Wilde 1954, 1958: Earthworm Mull; Wilde 1966: Vermiol (in part); Romell and Heiberg 1931: Crumb-mull; Bernier 1968: Fine Mull; Hartmann 1952: Milder Mull]

Characteristic humus form profile: (L), (Fa), Ah

Vermimulls are characterized by thin or discontinuous L and F horizons overlaying well formed, dark coloured, zoogenous Ah horizons. Specifically, the F horizons are < 1 cm, and the Ah horizons are >2 cm. H horizons, if present, are < 1 cm. The Ah horizons, which are always granular (crumb-like) in structure, have developed by the predominant activity of soil fauna, particularly earthworms. A strong organo-mineral complex ("clay-humus complex")[1] results from this activity. Earthworm casts are diagnostic for these horizons. Dense, fine roots in the Ah horizon are absent. The subgroups are derived from the size of the dominant granular structure.

Vermimulls show very rapid decomposition and synthesis of organic materials (thin or absent L and F). They are usually found in moisture and nutrient rich habitats in mesothermal and subtropical climates. Vermimulls are the characteristic humus forms of the most productive ecosystems for the growth of several coniferous tree species in southwestern British Columbia. They are usually associated with deciduous, coniferous-deciduous or coniferous stands, on well to poorly drained alluvial habitats, with an understory vegetation that yields easily decomposable deciduous litter.

Key to subgroups

2b1. Vermimulls in which the dominant size of granular aggregates is 2 - 5 mm

Orthivermimull

2b2. Vermimulls in which the dominant size of granular aggregates is < 2 mm

Microvermimull

2b3. Vermimulls in which the dominant size of granular aggregates is >5 mm

Macrovermimull

Description of an Orthivermimull

The following description of a humus form profile is characteristic of the central concept of the Vermimulls. The profile is located in MacMillan Park (Vancouver Island) in the Vancouver Forest Region. The ecosystem is classified as the Thuja (plicata) & Abies (grandis) - Pseudotsuga (menziesii) - Polystichum (munitun) - Tiarella (trifoliata) Association on a fine-loamy Orthic Humo-Ferric Podzol, Sombric phase formed on an alluvial terrace.

Horizon	Depth (cm)	Description
L	1-0	Moist; non-compact matted; loose; acerose; common insects, few mycelia; abrupt, broken boundary.
Ah	0-8	Moist; dark reddish brown (5 YR 3/2 m); strong, medium granular; friable; loam; plentiful, fine and medium roots; many earthworms; abrupt, irregular boundary.

33. Hydromull

Duchaufour 1960 [n.n.; Wilde 1958: Fenmull; Wilde 1966, 1971: Sapronel; Bernier 1968: Humic Peaty Mor (in part); Kubiena 1953: Anmoor]

Characteristic humus form profile: (L), (Fa), Ah(g)

Hydromulls are poorly aerated Mulls which are under the influence of prolonged but not permanent saturation. They typically possess thin L and F horizons overlaying the Ah(g) horizons. Due to the influence of a high water table, Oh horizons may form in the profile, but they never exceed the thickness of the underlying Ah(g). H or H horizons may occasionally be found in the profile.

Hydromulls develop under direct influence of fluctuating, slowly moving water generally located between 30 and 60 cm from the surface. The humus form remains saturated during wet periods of the year but becomes moist, at least in the upper profile, in response to a drop in the water table during summer months.

The Ah(g) horizons are typically very dark coloured due to significant amounts of finely dispersed, well humified organic matter. Their structure is generally subangular blocky or, occasionally, granular when moist. During saturated periods, the structure becomes massive with a mucky character. The mineral component of the Ah horizon originates largely from in-washing of mineral sediments.

Hydromulls are formed under the influence of hydrolysis and the intense activity of anaerobic organisms (Wilde 1958). Rich populations of aerobic organisms including earthworms may be present, particularly in the upper humus form profile where saturation is less prolonged. Chemical properties are characterized by high values of base saturation and mildly acid to neutral pH. Synthesis and decomposition of fresh organic materials proceeds rapidly.

Hydromulls are formed in temperate and mesothermal climates in physiographic or edaphic environments where prolonged saturation of the soil is common. Ground water feeding the sites is enriched with bases. Associated soils are either Gleysols, gleyed subgroups of other mineral soil orders with well expressed gleying within 50 cm of the surface, or occasionally organic soil.

Key to subgroups (Figure 12)

3a1. Hydromulls that conform to the central concept of the group

Orthihydromull

[1]Clay-humus complex refers to the stable binding of finely divided humus substances with clay mineral particles. Organic matter is precipitated onto surfaces of clay particles, forming a "pigment" (Babel 1975). Formation of these complexes is promoted by intimate blending of mineral and organic constituents in the gut of earthworms (Kubiena 1953). Although the concept of clay-humus complexes is valid, there is little analytical evidence to prove their existence in forest humus forms.

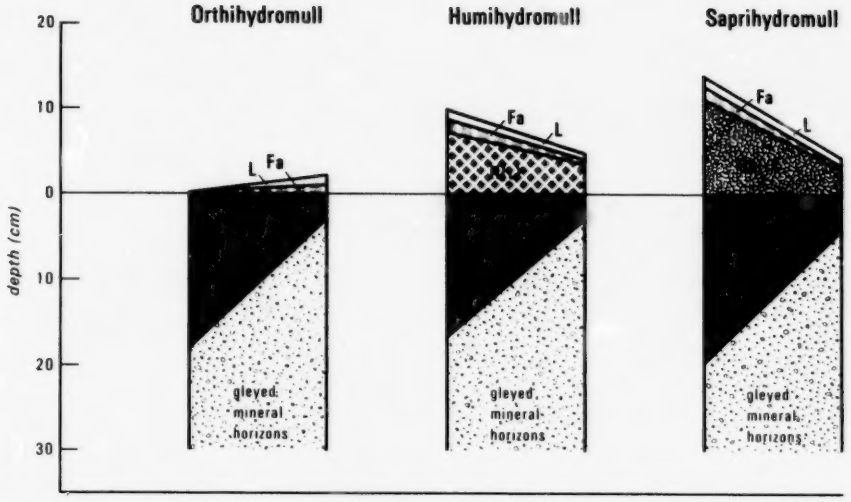

Figure 12. Characteristic humus form profiles of subgroups of the Hydromull group.

3a2. Hydromulls in which H(ι) horizons are present within the humus form profile. The thickness of the H(ι) is < the thickness of the Ah(g) horizons
Humihydromull

3a3. Hydromulls in which Oh or Ohι horizons are present within the humus form profile. The thickness of the Oh(ι) is < that of the Ah(g) horizons
Saprihydromull

Description of an Orthihydromull

The following description of a humus form profile has the characteristics of the central concept of Hydromulls. The profile is located in the U.B.C. Research Forest in the Vancouver Forest Region. The ecosystem is classified as the Thuja (plicata) - Rubus (spectabilis) - Polystichum (munitum) Association on a clayey Orthic Humic Gleysol formed on glaciolacustrine over glaciomarine materials.

Horizon	Depth (cm)	Description
L	2-0.5	Herbaceous foliage and moss tissues; moist; weak non-compact matted; leafy; loose; no roots; no visible biota; abrupt, wavy boundary.
H	0.5-0	Moist; weak, medium granular; greasy; very friable; few, fine roots; common, medium droppings; abrupt, wavy boundary.
Ah	0-20	Moist; very dark gray-brown (10 YR 3/2 m); medium, sub-angular blocky; clay loam; friable; abundant, fine to coarse roots; few earthworms in upper horizon; clear, wavy boundary.

34. Saprimull

[n.n; Bernier 1968: Humic Peaty Mor (in part); Kubiena 1953: Pitch Peat Anmoor (in part)]

Characteristic humus form profile:(L), (F), (Of), (Om), Ohι

Saprimulls are very poorly aerated Mulls which are under the influence of more or less permanent saturation. They are dominated by Ohι horizons, which always comprise more than 50% of the humus form profile. The characteristic horizon sequence includes thin L, F, Of or Om horizons, generally under 2 cm thick, overlaying the prominent Ohι horizons. These horizons may not contain incorporated mineral soil, in which case the Parasaprimull Subgroup is recognized. Associated soils are most frequently Organic. However, they may occasionally be formed on Gleysols.

Saprimulls develop under conditions of prolonged saturation from a stagnant water table, generally located within 30 cm of the ground surface. The humus form remains wet for the greater portion of the year with the upper horizons becoming moist for short periods during dry months.

The Ohι horizons are typically very dark coloured, with massive structure and greasy character. The horizon is generally always wet. The intermixed mineral particles generally originate from in-washed sediments.

Humification proceeds rapidly in Saprimulls. The minerotrophic groundwater which influences the humus form promotes chemical "weathering" and active decomposition by predominantly anaerobic organisms. Periodic aerobic decomposition may take place in the upper profile. However, decomposition products tend to accumulate due to excessive moisture. As in Hydromulls, chemical properties of Saprimulls are characterized by high values of base saturation, exchangeable bases, particularly Ca, and mildly acid to neutral pH.

Saprimulls are most frequently distributed in temperate and mesothermal climates in physiographic or edaphic environments where a high and permanent water table is common. Groundwater of ecosystems is always high in bases, particularly Ca. Ecosystems associated with Saprimulls are generally sparsely or non-forested with hydrophytic herbaceous vegetation predominating.

Key to subgroups (Figure 13)

3b1. Saprimulls in which the combined thickness of F, Of and Om horizons is < 2 cm. The remaining humus form profile is comprised of Oh horizons

Orthisaprimull

3b2. Saprimulls in which the combined thickness of F, Of and Om horizons is <2 cm. The remaining humus form profile is comprised of Oh horizons

Parasaprimull

3b3. Saprimulls in which F, Of or Om horizons are > 2 cm thick but do not exceed 50% of the total thickness of O horizons in the humus form profile

Histosaprimull

3b4. Saprimulls in which the combined thickness of F, Of and Om horizons is < 2 cm; H horizons are present but do not exceed the thickness of the Oh or Oh horizons

Humisaprimull

3b5. Saprimulls in which the combined thickness of F, Of and Om horizons is < 2 cm. Ah(g) horizons >5 cm thick are present within the humus form profile but do not exceed the thickness of the Oh or Oh horizons

Hydrosaprimull

Description of an Orthisaprimull

The following description of a humus form profile has the characteristics of the central concept of Saprimulls. The profile is located in the U.B.C. Research Forest in the Vancouver Forest Region. The ecosystem is classified as the Thuja (plicata) - Lysichitum (americanum) Association on a Typic Humisol, Lithic phase, formed on an organic veneer over quartzdiorite bedrock.

Horizon	Depth (cm)	Description
L	2-0	Red alder foliage; moist; non-compact matted; loose; leafy; no roots; few clusters of fine, white mycelia; abrupt, broken boundary.
Oh	0-45	Wet; very dark gray (10 YR 3/1 m); weak; coarse, sub-angular blocky to massive; greasy; pliable; common, fine roots in upper horizon; no visible biota; abrupt, wavy boundary.

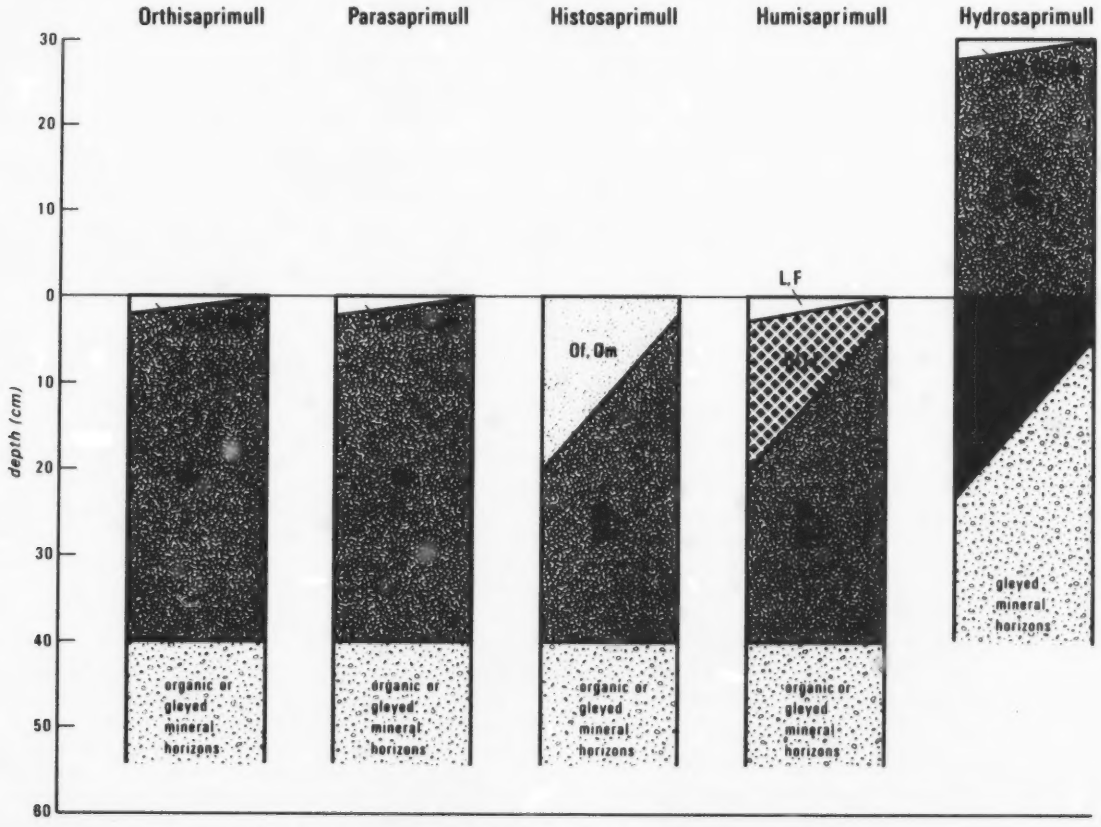

Figure 13. Characteristic humus form profiles of subgroups of the Saprimull group.

Testing of the Classification

The proposed taxonomic classification of humus forms was tested to substantiate the significance of the differentiated taxa. The testing was carried out in relation to a range of chemical properties[1]. It was designed to demonstrate the relationships of taxa to the properties which had not been used as differentiae. The results presented have several limitations: they are based on materials from a small geographical area, hence, only some taxa of the present system are included; they deal only with orders and groups, since properties needed for classification of subgroups were not consistently described; the parameters analyzed may not represent those chemical properties which reveal the different nature of humus forms; and, finally, the results for categories are evidently dependent on the representation of classes in each category. In this test, representation for some classes may not be adequate, so the reader is cautioned to view the presented data with this in mind.

Sampling was done during a synecological study conducted by Klinka (1976) at the University of British Columbia Research Forest near Haney, approximately 60 km east of Vancouver in southwestern British Columbia.

The study was carried out in that portion of the Forest located within the Coastal Western Hemlock (CWH) Biogeoclimatic Zone of British Columbia. The area is characterized by a mesothermal climate and is underlain by acid igneous rocks, mainly quartzdiorite. Glacial till is the most common parent material with loose till, frequently overlying compacted till. The soils are typically coarse-textured, contain a high amount of coarse fragments and are acidic with acidity decreasing with depth. The soils are classified mainly as Humo-Ferric or Ferro-Humic Podzols (CSSC 1978) with prevailing Mor humus forms. The forests are dominated by western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] but contain significant amounts of western redcedar (*Thuja plicata* Donn *ex* Don in Lamb). Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] is common at lower elevations and amabilis fir [*Abies amabilis* (Dougl.) Forbes], at higher elevations.

Composite samples of ectorganic horizons in the humus form profiles were collected from the 166 pedons within a number of ecosystems (biogeocoenoses) representing a wide range of ecological conditions and productivity levels. Using the present system, the following humus form groups were identified: Hemimor, Humimor, Hydromor, Mormoder, Hydromoder, Vermimull, and Hydromull. A more complete description of the study area, sample preparation and analytical methods has been given by Klinka (1976).

The samples were analyzed for pH (in H_2O), organic matter content (OM%), total nitrogen (N%), exchangeable cations (Ca, Mg, Na and K) and cation exchange capacity (CEC, in NH_4OAC extraction, pH 7), and total Ca, Mg, Na, K, Fe, Al and Mn. Carbon:nitrogen (C/N) ratio and base saturation (BS%) were calculated. These parameters plus thickness of ectorganic horizons in the humus form profile were the seventeen variables used in testing. Analytical methods were those used in the Pedology Laboratory Manual (Lavkulich 1978).

A discriminant analysis was employed to determine relationships of the differentiated taxa to the above chemical properties. The number of recognized taxa is the same as the number of groups used in the analysis. Using discriminant analysis, one can mathematically select the chemical parameter(s) which in combination are able to separate the taxa recognized independently. Each group is characterized by a unique linear function, which in this case is generated from the chemical parameters which best serve to distinguish between the groups.

A stepwise discriminant analysis was performed on the data using a computer program (Halm 1970) available at the Computing Centre, University of British Columbia. F-probability for inclusion and deletion of parameters (variables) were 0.100 and 0.101, respectively. In the analysis, the chemical parameters are entered into linear functions in a stepwise manner. Each time a parameter is added, a statistical test is done to determine if the distinction between the groups has increased. If its inclusion is not beneficial, it is dropped; otherwise, it is retained. The usefulness of each parameter is tested every time a new one is added, and those no longer making a significant contribution are dropped. Parameters are ranked according to their performance in maintaining the group separation. This order of importance is displayed in the following tables. In addition, canonical variables for each parameter chosen for the discriminant function are calculated and plotted to give a two-dimensional illustration of the degree of separation of groups. The calculation of canonical variables is from the statistics for the chemical parameters and can be used only on a relative basis. For specific formulae concerning any steps described, the reader should consult the documentation available at the University of B.C. Computing Centre.

The entire set of chemical data for 166 humus forms was subjected to discriminant analysis to distinguish between the three orders, Mor, Moder and Mull. The chemical properties conform closely to the original classification; nearly 90 percent of the samples were separated into the three orders on the basis of chemical properties (Table 11).

TABLE 11. *Classification Table — Percentage of Humus Forms Classified into Each Order*

Original classification	Discriminant analysis		
	Mor	Moder	Mull
Mor	98	2	0
Moder	11	80	9
Mull	0	20	80

It appears that the morphological properties of Mors correlate well with common chemical properties, while for Moders and Mulls, there is some overlap. Since Mod-

[1]Similar testing involving organic and inorganic constitutents of humus forms has been carried out in the CWH Zone by Klinka and Lowe (1975, 1976a, 1976b) and Lowe and Klinka (1981).

ers are considered by many workers to be transitional between Mors and Mulls, the suggested "misclassification" of 20% of the Moders is not surprising. However, this could also be indicative of errors in the original classification, in which case it may reveal problems in the identification of those humus forms described in the absence of the currently applied standards. Discriminant analysis provides an efficient basis for examining such discrepancies because the "misclassified" samples can be identified. However, the possibility that morphologically similar humus forms may differ in other properties cannot be ruled out.

TABLE 12. *Means and Standard Deviations for Discriminating Chemical Properties of Mor, Moder, and Mull Orders in the U.B.C. Research Forest*[1]

Humus form order	Mor	Moder	Mull
Number of samples	25	56	25
Discriminating parameters			
Reaction (pH)	3.8 (0.27)[2]	4.3 (0.41)	5.1 (0.47)
Carbon:nitrogen ratio	38.1 (9.24)	24.8 (5.98)	22.0 (5.66)
Base saturation (%)	12.4 (5.65)	17.9 (9.49)	40.1 (17.46)
Total magnesium (ppm)	730 (428)	1840 (1349)	2600 (1370)
Cation exchange capacity (meq/100 gm)	122.3 (37.19)	102.5 (29.83)	102.2 (126.85)
Exchangeable potassium (meq/100 gm)	1.91 (0.962)	1.11 (0.533)	1.55 (0.821)
Total aluminum (ppm)	8190 (11452)	14380 (12879)	14610 (11509)
Total iron (ppm)	6230 (5060)	16670 (14971)	14070 (10707)
Total nitrogen (%)	1.28 (0.275)	1.53 (0.390)	1.74 (0.426)
Total sodium (ppm)	140 (40)	180 (74)	190 (76)
Exchangeable magnesium (meq/100 gm)	2.25 (0.893)	2.72 (1.479)	4.63 (2.337)
Remaining parameters			
Thickness of humus form (cm)	13.1 (10.77)	8.3 (5.85)	6.8 (10.33)
Organic matter (%)	80.0 (11.88)	64.6 (18.51)	65.6 (17.00)
Exchangeable calcium (meq/100 gm)	9.28 (4.538)	14.29 (8.558)	32.02 (16.199)
Total calcium (ppm)	3650 (1524)	6450 (2948)	13000 (4822)
Total potassium (ppm)	840 (304)	890 (450)	1100 (349)
Total manganese (ppm)	260 (309)	1230 (1793)	1410 (1988)

[1]Based on ectorganic portion of humus forms.
[2]Numbers in parenthesis are standard deviations.

Eleven variables, among them pH and C/N ratio, were selected as contributing significantly to the discriminant functions. They are located in the order of importance from top to bottom in Table 12. Six variables, among them thickness of ectorganic horizons and organic matter content, were not included, mainly because of similar values throughout the whole set or large values of standard deviations. The plot of canonical variables shows the relationship between Mor, Moder and Mull orders (Figure 14). Despite a considerable dispersion around means for orders, separation into three clusters is evident. On the other hand, it is also apparent that affinities exist between orders, which points out the continuous nature of humus forms.

Other humus forms can now be classified into orders on the basis of this chemical analysis using computed linear functions (Table 13).

TABLE 13. *An Example of Classification Functions Determined in the Discriminant Analysis*

Humus form order		Mor	Moder	Mull
Constant		−195	−224	−270
Parameter				
Reaction (pH)	X1	50.22	56.57	57.91
Carbon:nitrogen ratio	X2	2.343	2.217	2.332
Base saturation (%)	X3	−0.530	−0.554	−0.0856
Total magnesium (%)	X4	0.0073	0.0083	0.0099
Cation exchange capacity (meq/100 gm)	X5	−0.0056	−0.0100	0.0222
Exchangeable potassium (meq/100 gm)	X6	−0.543	−1.175	−1.745
Total aluminum (ppm)	X7	−0.0010	−0.0012	−0.0011
Total iron (ppm)	X8	0.0004	0.0006	0.0005
Total nitrogen (ppm)	X9	67.53	71.87	79.15
Total sodium (ppm)	X10	0.238	0.246	0.286
Exchangeable magnesium (meq/100 gm)	X11	−2.379	−2.102	−3.009

Using the above table, it can be determined that the functions are:

$$Y_{MOR} = -195 + 50.22\,(X1) + 2.343\,(X2) - 0.530\,(X3) \ldots\ldots - 2.379\,(X11)$$

$$Y_{MODER} = -224 + 56.57\,(X1) + 2.217\,(X2) - 0.554\,(X3) \ldots\ldots - 2.102\,(X11)$$

$$Y_{MULL} = -270 + 57.91\,(X1) + 2.332\,(X2) - 0.0856\,(X3) \ldots\ldots - 3.009\,(X11)$$

The data are classified into the group with the largest Y value.

In the next step, the data set for the Mor Order, including 85 samples, was subjected to discriminant analysis to distinguish between the three groups, Hemimor, Humi-

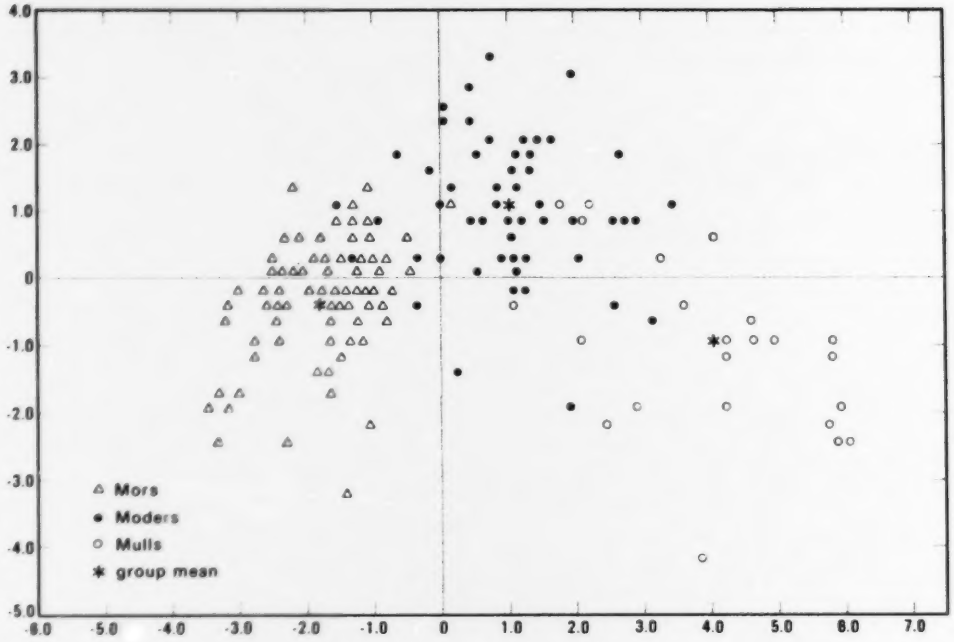

Figure 14. The plot of canonical variables for chemical properties which were used to discriminate between Mors, Moders, and Mulls.

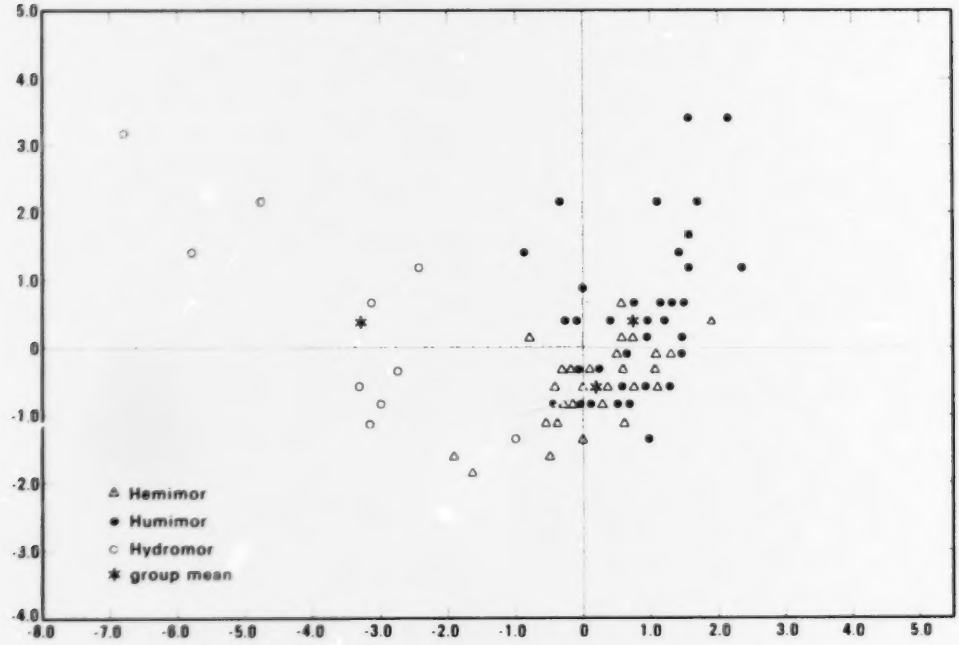

Figure 15. The plot of canonical variables for chemical properites which were used to discriminate between Hemimors, Humimors and Hydromors.

mor and Hydromor. The chemical properties, however, conform less satisfactorily to the original classification; only 68 percent of sample forms separated into the three groups (Table 14).

TABLE 14. *Classification Table — Percentage of Humus Forms Classified into Each Group*

Original Classification	Discriminant analysis		
	Hemimor	Humimor	Hydromor
Hemimor	70	27	3
Humimor	38	62	0
Hydromor	18	0	82

Canonical variables complement the results given in the classification table (Figure 15). While the Hydromor humus form appear to be well separated, a considerable overlap exists between Hemimors and Humimors.

Assuming that the identification of F and H master horizons was correct, it might be found that the "misclassification" is due to the fact that an intermediate class between Hemimors and Humimors had not been recognized in the study used for the testing, while the Hemihumimor, which includes in part, Bernier's (1968) Fibri-Humimor and Humi-Fibrimor, is recognized in the present system. It is also possible that a satisfactory separation based entirely on these chemical properties cannot succeed. This should be determined by further studies. The minor non-conformity in the classification of Hydromors may be related to uncertainty in the identification of F and Om horizons, or it may indicate affinities in chemical properties between Hemimors and Hydromors. A Hemihydromor group in this taxonomy has been provided for such segregation.

Five variables were selected as contributing significantly to the discriminant functions. They are listed in order of importance in Table 15. Total Mg and C/N ratio had been used previously, whereas total Ca, thickness, and total Al were added to discriminate between the groups of the Mor order. A low content of total Ca and a high content of total Al, which are characteristic for the Hydromors, contributed to their separation from Hemimors and Humimors.

The data set for the Moder Order, including 56 samples, was subjected to discriminant analysis to distinguish between the two groups, Mormoder and Hydromoder. The chemical properties conform well to the original classification; 80 percent of samples were identically classified (Table 16).

TABLE 16. *Classification Table — Percentage of Humus Forms Classified into Each Group*

Original classification	Discriminant analysis	
	Mormoder	Hydromoder
Mormoder	81	19
Hydromoder	25	75

TABLE 15. *Means and Standard Deviations for Discriminating Chemical Properties of Hemimor, Humimor and Hydromor Groups in the U.B.C. Research Forest*

Humus form group	Hemimor	Humimor	Hydromor
Number of samples	37	37	11
Discriminating parameters			
Total calcium (ppm)	3750 (1183)[1]	4290 (1188)	1150 (995)
Thickness (cm)	8.7 (5.20)	17.3 (13.49)	14.2 (9.28)
Total magnesium (ppm)	740 (424)	840 (423)	350 (213)
Total aluminum (ppm)	4950 (5315)	5780 (5020)	27180 (21263)
Carbon:nitrogen ratio	36.0 (5.50)	39.2 (11.88)	41.0 (8.42)
Remaining parameters			
Organic matter (%)	81.3 (10.91)	78.6 (12.04)	80.7 (14.87)
Reaction (pH)	3.7 (0.23)	3.8 (0.17)	4.2 (0.44)
Total nitrogen (%)	1.33 (0.229)	1.25 (0.784)	1.19 (0.366)
Exchangeable calcium (meq/100 gm)	9.89 (3.821)	10.49 (4.198)	3.18 (3.048)
Exchangeable magnesium (meq/100 gm)	2.38 (0.762)	2.40 (0.771)	1.31 (1.168)
Exchangeable potassium (meq/100 gm)	2.16 (1.051)	1.79 (0.869)	1.51 (0.793)
Cation exchange capacity (meq/100 gm)	115.3 (33.35)	130.9 (37.73)	116.6 (44.71)
Base saturation (%)	13.8 (5.04)	12.3 (3.78)	7.7 (9.68)
Total sodium (ppm)	140 (40)	140 (41)	140 (42)
Total potassium (ppm)	920 (336)	770 (264)	790 (275)
Total iron (ppm)	4820 (3990)	7000 (6303)	8040 (9798)
Total manganese (ppm)	300 (254)	240 (306)	230 (472)

[1]Numbers in parenthesis are standard deviations.

Only two variables, organic matter content and total Fe, were selected as contributing significantly to the discriminant functions. They are listed in order of importance in Table 17 and are followed by the remaining variables. For the most part, there are close affinities between the properties listed for these two groups. A relatively low organic matter content in the organic horizons seems to be a common characteristic for Mormoders. Similarly, total Fe appears to increase with increasing mineral matter content as well as moisture content.

The classification discrepancies between Mormoders and Hydromoders may be related either to an uncertainty in the identification of terrestrial and semi-terrestrial organic horizons or to the possibility that a perfect separation based entirely on these chemical properties cannot succeed.

TABLE 17. *Means and Standard Deviations for Discriminating Variables of Mormoder and Hydromoder Groups in the U.B.C. Research Forest*

Humus form group	Mormoder	Hydromoder
Number of samples	48	8
Discriminating parameters		
Organic matter (%)	62.3 (18.44)[1]	78.4 (12.56)
Total iron (ppm)	16260 (15013)	19160 (15047)
Remaining parameters		
Thickness (cm)	7.6 (5.31)	12.1 (7.77)
Reaction (pH)	4.3 (0.40)	4.4 (0.42)
Total nitrogen (%)	1.50 (0.389)	1.76 (0.336)
Carbon:nitrogen ratio	24.4 (5.33)	27.0 (9.16)
Exchangeable calcium (meq/100 gm)	14.21 (8.787)	14.78 (7.528)
Exchangeable magnesium (meq/100 gm)	2.69 (1.493)	2.91 (1.468)
Exchangeable potassium (meq/100 gm)	1.14 (0.550)	0.91 (0.383)
Cation exchange capacity (meq/100 gm)	101.7 (31.85)	107.6 (12.08)
Base saturation (%)	18.0 (9.87)	17.5 (7.28)
Total calcium (ppm)	6600 (3073)	5550 (1952)
Total magnesium (ppm)	1990 (1387)	910 (489)
Total sodium (ppm)	180 (79)	150 (34)
Total potassium (ppm)	940 (459)	580 (229)
Total aluminum (ppm)	13840 (12649)	17620 (14661)
Total manganese (ppm)	1100 (1501)	2050 (3021)

[1]Numbers in parenthesis are standard deviations.

The data set for the Mull Order, including 25 samples, was subjected to discriminant analysis to distinguish between the two groups, Vermimull and Hydromull. The chemical properties conform well to the original classification; 84 percent of samples were identically classified (Table 18).

TABLE 18. *Classification Table — Percentage of Humus Forms Classified into each Group*

Original classification	Discriminant analysis	
	Vermimull	Hydromull
Vermimull	84	16
Hydromull	17	83

Only two variables, C/N ratio and total Al, were selected as contributing significantly to the discriminant functions. They are listed in order of importance together with the remaining variables in Table 19. Total Al and/or Fe appear to be useful in separating humus forms (Hydromors, Hydromoders, Hydromulls) under the permanent influence of excessive moisture. However, the selection of a nearly identical C/N ratio as a discriminating variable between the Vermimulls and Hydromulls was not expected and was attributed to different values for the standard deviations of the respective means.

TABLE 19. *Means and Standard Deviations for Discriminating Variables of Vermimull and Hydromull Groups in the U.B.C. Research Forest*

Humus form group	Vermimull[1]	Hydromull[1]
Number of samples	19	6
Discriminating parameters		
Carbon:nitrogen ratio	22.1 (4.74)[2]	21.8 (8.52)
Total aluminum (ppm)	10460 (6503).	27760 (14521)
Remaining parameters		
Thickness (cm)	3.7 (14.49)	16.7 (17.96)
Organic matter content (%)	69.4 (3.23)	53.5 (19.98)
Reaction (pH)	5.0 (0.52)	5.1 (0.29)
Total nitrogen (%)	1.83 (0.432)	1.44 (0.254)
Exchangeable calcium (meq/100 gm)	34.64 (16.619)	20.57 (7.624)
Exchangeable magnesium (meq/100 gm)	5.21 (2.382)	2.79 (0.675)
Exchangeable potassium (meq/100 gm)	1.61 (0.733)	1.38 (1.119)
Cation exchange capacity (meq/100 gm)	133.1 (143.87)	79.1 (7.96)

TABLE 19. *Means and Standard Deviations for Discriminating Variables of Vermimull and Hydromull Groups in the U.B.C. Research Forest* - Continued

Humas form group	Vermimull[1]	Hydromull[1]
Base saturation (%)	42.8	31.6
	(18.95)	(7.36)
Total calcium (ppm)	13640	10980
	(5703)	(2769)
Total magnesium (ppm)	2490	2960
	(1311)	(1617)
Total sodium (ppm)	173	263
	(64.4)	(80.9)
Total potassium (ppm)	1110	1060
	(346)	(388)
Total iron (ppm)	11350	22670
	(8823)	(12381)
Total manganese (ppm)	960	2810
	(933)	(3568)

[1]Values refer to ectorganic horizons (mainly litter materials) above Ah horizons, or to Oh horizons.
[2]Numbers in parenthesis are standard deviations.

The classification discrepancies likely originated from using ectorganic horizons (for the most part, litter materials) as representative of Vermimulls. Although a discrimination using organic horizons could be successful, representing "terrestrial" Mulls by diagnostic mineral horizons is considered to be more meaningful. However, not all Mulls, particularly those under the permanent influence of excessive moisture, need to have a dark-coloured surface mineral horizon enriched in organic matter in the control section. Consequently, the representation of Mull humus forms by both mineral and organic horizons seems to be unavoidable.

In general, discriminant analysis substantiated the significance of the differentiated taxa recognized on the basis of morphological properties. It showed that morphological properties can be used as predictors of chemical properties (inorganic constitutents), thus confirming the approach adopted for humus form classification. It also provides an efficient tool for examining the nature of any differences which are found and can provide equations for numerical classification. For these reasons, it should be used in testing the system, in preparing a key to the classification and in determining quantitative properties; a more precise definition of taxa in the system will result.

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Appendices

Appendix I

Methods of Describing Humus Forms

A horizon approach to the description of humus forms has been adopted. In making humus form examinations, all distinguishable horizons and layers are separately described. According to Soil Survey Staff (1975) "these descriptions need to be completely objective and clearly able 'to stand on their own', regardless of presumed genesis or nomenclature. Nothing can substitute for them. The more laboratory data there are available for collected samples, the more important the descriptions become; without them, the laboratory data cannot be safely interpreted; if indeed, they are relevant at all."

The properties that will be described may not be found in each horizon or layer and may not be used as taxonomic differentiae. However, as in describing a soil pedon, a complete description of morphological properties for humus forms is recommended. Morphological properties are described in the field using the naked eye and a hand lens (10× to 20×). A binocular scope is used for a more detailed examination in the laboratory.

In describing a humus form, one usually locates the boundaries of the control section, decides about the limits of the humus form profile, locates the boundaries between horizons, and examines the profile as a whole before naming and describing the individual horizons. Sampling for physical and chemical analysis of individual horizons, or horizon combinations (composite samples) is carried out as required.

The written description of individual horizons in the humus profile includes identification and listing of the following attributes in this sequence: horizon designation and thickness, kind of materials, moisture status, colour, fabric, roots, non-conforming materials, biota, reaction, and boundaries. Reaction is determined according to mode of sampling.

Some aspects of the description are presented in detail by the Working Group on Soil Survey Data [Dumanski (ed.) 1975] in the "CanSIS Manual for Describing Soils in the Field". The CanSIS Manual is used to describe the properties of all mineral horizons and some properties of the O horizons. Since no terms or methods are available for describing the properties of the L, F and H horizons, this Appendix provides such a methodology.

Horizon Designation, Depth and Boundaries

Once master horizons in the humus form profile have been identified, they have to be subdivided in the manner previously indicated in the text so that descriptions are correctly recorded and the sampling of humus forms proceeds in an organized fashion. Laboratory work may be needed for positive identification of the kind of horizon.

In a mineral soil, the top of the first mineral horizon has zero depth; in an organic soil the top of the first recognized horizon has zero depth. Thus, the depth of organic horizons in mineral soils is measured upward from zero depth, whereas in organic soils the depth is measured downward from zero depth. Thickness measurements are indicated in terms of mean, minimum and maximum thickness in centimetres. The proposed minimum thickness for describing and sampling humus form horizons is 0.5 cm.

Boundaries are classified according to their distinctions and form using the following scales (Table 1 and 2):

TABLE 1. *Boundary - Classes of Distinctness*

Class	Description
Abrupt	< 5 mm
Clear	5 - 10 mm
Gradual	11 - 20 mm
Diffuse	> 20 mm

TABLE 2. *Boundary - Classes of Form*

Class	Description
Smooth	Nearly a plane
Wavy	Pockets wider than deep
Irregular	Pockets deeper than wide
Broken	Discontinuous, some parts are unconnected

Moisture Status

Some morphological properties of materials described may be affected by their moisture content. Therefore, as in the description of the whole pedon, the moisture status of horizons at the time of sampling (otherwise a transient property) is indicated using the scale in Table 3.

TABLE 3. *Classes of Moisture Status*

Class	Description
Desiccated	Extremely dry condition; organic tissues will crack or snap when broken or crushed
Dry	Moisture is not apparent; material will not rub colour out on fingers
Moist	Moisture is apparent; colour will rub out on fingers; if material is squeezed in hand, no water will be observed (generally below field capacity)
Wet	If material is squeezed or rubbed in hand, water will be observed (generally above field capacity)
Saturated	Water is observed without squeezing or rubbing of material

Colour

The colour property of materials is classified according to its hue, value and chroma, using the Munsell colour notations when possible. Rubbed field colours (according to field moisture status at the time of description) and dry colours (following the sample preparation for analysis) are recorded.

The colour selection available for describing soils might not be sufficient for describing organic materials, e.g. for bright red colour of decaying wood. And, due to the prevailing grey hue, the colour of organic and mineral materials within the humus form profile may be of less interpretive significance than that for mineral soil horizons. However, colour is still used as an indirect measure of characteristics or qualities which cannot be easily or accurately observed. Colour is applied as one of the differentiae identifying Ah and Hr horizons.

Consistence

Consistence is a measure of the strength and nature of forces combining materials together, which is determined by the kind of deformation or rupture which occurs when pressure is applied and then released.

TABLE 7. *Consistence - Classes of Consistence*

Class	Description
Loose	There is no consistence of the material
Friable	A material that crumbles easily under gentle pressure
Firm	A material that can be crushed under moderate pressure; resistence is noticeable
Pliable	Material is soft and plastic
Resilient	Material that is springy or elastic and assumes original state after forces of deformation have been applied and released
Tenacious[1]	Material is cohesive, not easily pulled apart

[1]Degree of tenacity may be further described as weak, medium or strong.

Character

There are certain terms which have been found useful in describing the distinctive quality (tactility) of materials in the humus form profile. They are listed and defined in Table 8 and may be used where applicable. Among them are terms which describe tactile qualities, particulate shapes, and other noteworthy qualities. Determining the character requires a qualitative examination of the fabric.

TABLE 8. *Classes of Character*

Class	Description
Mushy	Materials are wet or saturated, soft and spongy
Mucky	Materials are usually wet, smooth and sticky; they contain silt and clay sized mineral particles
Greasy	Materials are smooth and greasy when moist and easily workable; fine mineral particles are usually absent
Gritty	Refers to a rough tactility produced by mineral granules or coarse fragments
Leafy	Refers to the tactility of materials produced by deciduous foliage showing a shingle-like layering (banded structure)
Mossy	Refers to the tactility produced by bryophytes with more or less preserved vegetative structures
Acerose	Refers to the tactility produced by particles having a tip, as the needles of conifers
Felty	Refers to the tactility produced by abundant fungal mycelia
Fibrous	Refers to tactility produced by an abundance of fibrous plant residues which do not break down upon rubbing (*ie.* fine roots)
Ligneous	Refers to the tactility produced by coniferous or deciduous wood fibres
Crusty	Refers to a hard and brittle tactility of dry or desiccated materials

Fabric

The terms "fabric" and "fabric analysis" have been used in studies of soil and humus (Kubiena 1953, Brewer 1964, Babel 1975, Soil Survey Staff 1975, and Agriculture Canada 1976). In this study, the term fabric has been applied to the description of structure, consistence and character of organic materials in the humus profile. The term "materials" refers here to plant residues and/or organic fine substances, with or without a minor mineral component.

Structure

Structure is classified according to the grade, type and kind and size, of the macromorphological aggregation of the material within a horizon or layer.

The grade is the degree of distinctions of arrangement of what is observable in materials (Table 4).

TABLE 4. *Structure - Classes of Grade*

Class	Description
Weak	Disaggregated materials are dominant; < 20% distinction of aggregation.
Moderate	Some disaggregated material is found; 20 - 60% distinction of aggregation
Strong	Aggregated materials are dominant; most material conforms to the same arrangement; >60% distinction of aggregation.

The type of structure is divided into four classes. The first indicates that there is no structure (random); the second that the predominant structure is blocklike; the third that it is platelike; and the fourth that it is columnlike. The types are further classified according to kinds of structure (Table 5, Figure 1).

Blocklike structures are further classified in accordance with the scale in Table 6.

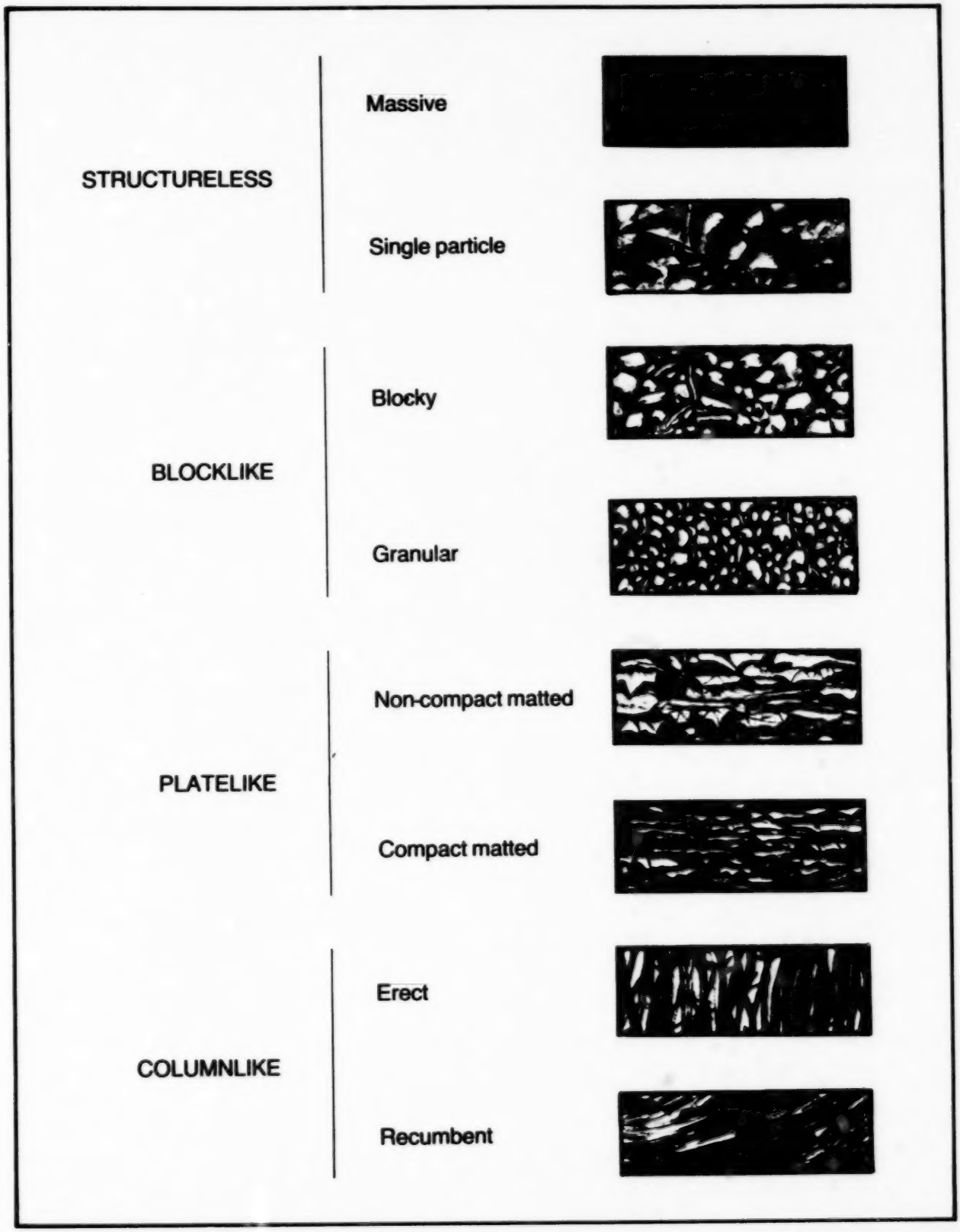

Figure 1. Schematic illustrations of classes of types and kinds of structure.

TABLE 5. *Structure - Classes of Type and Kind*

Type		Kind	
Class	Description	Class	Description
Structureless	No observable aggregation	Massive	A coherent mass showing no evidence of aggregation
		Single particle	An incoherent mass of individual particles (may be of various sizes) with no aggregation
Blocklike	Materials arranged around a point bounded by flat or rounded surfaces	Blocky	Faces rectangular and flattened; vertices sharply angular
		Granular	Spheroidal and characterized by rounded or subrounded vertices
Platelike	Materials arranged horizontally and parallel to each other, generally bounded by relatively flat horizontal surfaces	Non-compact matted	Materials arranged along horizontal planes with no compaction
		Compact matted	Materials arranged along horizontal planes with evident compaction
Columnlike	Materials arranged vertically	Erect	Materials in vertical position
		Recumbent	Materials in recumbent (reclining) position

TABLE 6. *Structure - Classes of Size for Blocklike Aggregates*

Class	Description
Fine	< 5 mm
Medium	5 - 20 mm
Coarse	>20 mm

Roots

Roots are described by noting their abundance, size and orientation (Table 9, 10 and 11). Distribution of roots, i.e. inped or exped, is described only for mineral horizons. Since the mode of root pattern in humus forms differs substantially from that in the rest of the pedon, the abundance and size scales and the reference unit area in the CanSIS Manual were modified to provide for more precise root description. Both classes are biased toward small-sized roots prevailing in the humus form profile. The reference unit area surface is 2.5 × 2.5 cm square for fine and very fine roots and 25 × 25 cm square for medium, coarse and very coarse roots. Presently, all living and dead roots are to be counted due to the difficulties involved in distinguishing the two. If roots are obviously dead, they may be excluded. If possible, record the species or general type of plant (*ie.* tree, shrub, etc.) from which roots originate.

TABLE 9. *Roots - Classes of Abundance*

Class	Number of roots/unit area surface
Very few	< 3
Few	3 - 10
Common	11 - 20
Plentiful	21 - 30
Abundant	>30

TABLE 10. *Roots - Classes of Size*

Class	Size (diameter in mm)
Very fine	< 1
Fine	1 - 2
Medium	3 - 10
Coarse	11 - 25
Very Coarse	>25

TABLE 11. *Roots - Classes of Orientation*

Class	Description
Random	Roots are oriented in all directions
Oblique	Roots are oriented along oblique planes
Horizontal	Roots are oriented along horizontal planes
Vertical	Roots are oriented along vertical planes

Non-Conforming Materials

Some materials may not conform to most of the organic materials comprising the humus form. They seem to persist for longer periods of times as admixtures to the materials in the horizons, or they may form a distinct horizon in the humus form profile.

The most commonly encountered non-conforming materials are charcoal, decaying wood and mineral coarse fragments. Their description includes the kind of material, their distribution, size and abundance; but it is given only when they form an admixture to prevailing materials in horizons.

Non-conforming materials are either distributed throughout (regular distribution) or distributed only in certain parts of the horizon (irregular distribution). Thus classification according to the general kind of material is

followed by a description of the specific kind of distribution.

Distribution and size of the non-conforming materials are described using common scales (Table 12 and 13).

TABLE 12. *Non-Conforming Materials - Classes of Distribution (after Brewer 1964)*

Class	Description
Random	Materials are distributed randomly; there is no recognizable, specific pattern of distribution
Clustered	Materials are distributed in clusters or groups
Banded	Materials are distributed in bands, sheets or layers

TABLE 13. *Non-Conforming Materials - Classes of Size*[1]

Class	Diameter (mm)	Length (mm)
Very fine	< 2	< 5
Fine	2 - 10	5 - 20
Medium	11 - 50	21 - 100
Coarse	51 - 250	101 - 500
Very coarse	> 250	> 500

[1]The diameter measurements are used for rounded or subrounded particles; the length measurements are used for particles with distinctly uneven axes.

Abundance refers to the volume occupied by non-conforming materials for each size class (Table 14) expressed as a percentage of the horizon volume.

TABLE 14. *Non-Conforming Materials - Classes of Abundance*

Class	Description
Few	Occasional and scattered pieces; volume < 5%
Common	Frequent occurence; volume 5 - 20%
Many	Numerous, usually coarse pieces; volume > 20%

Other relevant characteristics of non-conforming materials such as colour, degree of decomposition, origin, etc. may be recorded.

Biota

The activity of soil flora and fauna play such an important role in humus formation that their description cannot be overlooked. For the purpose of humus form description and taxonomy, the emphasis is placed on general qualitative and quantitative description.

Soil Fauna

Soil fauna are those animals that "pass one or more active stages wholly or largely in the soil or surface litter, excluding those species which occur there only in passive stages *e.g.* eggs, cysts or pupae (Richards 1974, Figure 2). The activity of fauna in the soil has a profound influence on humus formation. Through processes of burrowing, comminution and ingestion, soil fauna may participate actively in decomposition, in synthesis of humus materials and in the intermixing of humus and the mineral soil.

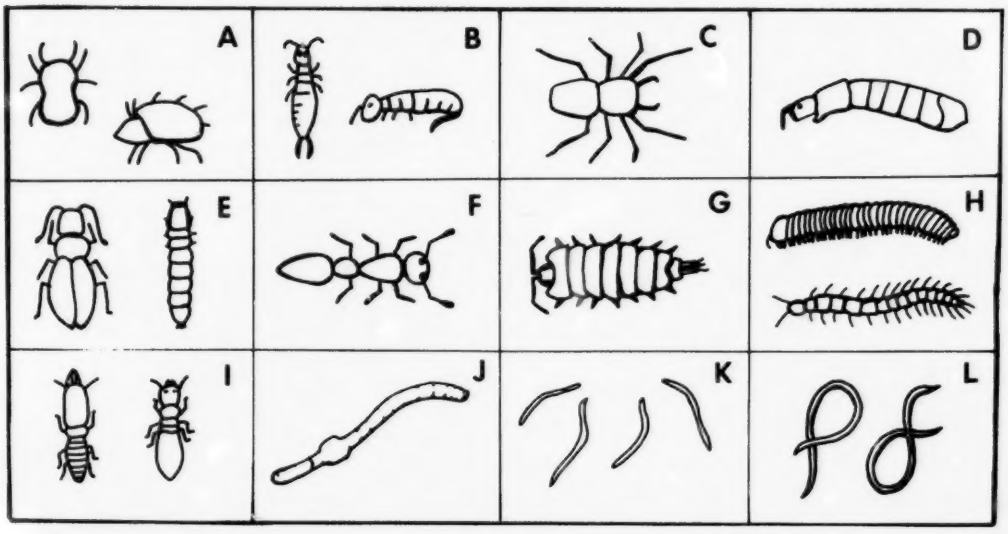

Figure 2. Major kinds of animals found in the soil.

Explanation of symbols in Figure 2:

A. Mites (Acarina)
B. Springtails (Collembola)
C. Spiders (Areneida)
D. Fly larvae (Diptera)
E. Beetles and larvae (Coleoptera)
F. Ants (Hymenoptera)
G. Woodlice (Isopoda)
H. Centipedes and millipedes (Myriapoda)
I. Termites (Isoptera)
J. Earthworms (Lumbricida)
K. Potworms (Enchytraeida)
L. Nematodes (Nematoda)

These classes may be further grouped into three broad classes according to body size (Table 15).

TABLE 15. *Size Classes of Soil Fauna (after Arnson 1977)*

Size Class	Description
Macrofauna	Animals with a body size greater than 1 cm (in the longest dimension); includes earthworms, vertebrates, molluscs and large arthropods
Mesofauna	Animals with a body size in the range of 1 cm to 0.2 mm includes some mites and springtails, potworms and most of the larger nematodes. The lower limit is about the limit of viewing with a 10 × hand lens.
Microfauna	Organisms less than 0.2 mm in size; includes the protozoa as well as many of the smaller mites and nematodes

Faunal populations may be determined by direct observation or by indirect observation through the presence of droppings or casts.

a) direct observation - an estimate of the relative abundance of soil fauna observed in the humus form may be made providing that discriminations can be made in terms of the general kinds and size classes described previously. The following classes of abundance may be used (Table 16):

TABLE 16. *Soil Fauna - Classes of Abundance*

Class	Description
None	No organisms observed
Few	Organisms occasionally observed, but only scattered
Common	Organisms observed commonly
Abundant	Organisms observed frequently throughout the profile.

b) indirect observation - a good indication of the activity of insects may be provided by their excrement ("droppings" or "casts") found within the horizon. Droppings constitute a significant portion of many organic horizons and in some cases can form entire horizons (Figure 3).

The following general types of droppings can be recognized using a hand lens or binocular scope (from Hodgson 1978):

i) Mite-type: usually formed by mites, Collembola, and Diptera larvae. Small (< 0.1 mm in diameter), discrete, spherical or oval, humified, rust to dark brown, lacking mineral grains.
ii) Enchytraeid-type: associated particularly with enchytraeid populations. Small (0.05 - 0.2 mm), discrete, sub-spherical, rugose, generally well-humified, brown, but containing varying amounts of mineral grains and clay.
iii) Arthropod-type: formed by larger arthropods and small surface-feeding earthworms. Visible to the naked eye (1.0 - 3.0 mm long), discrete, well-humified, dark brown, containing mineral grains but low in clay.
iv) Wormcasts: largely due to surface-casting earthworms. Well-humified, generally brown or greyish brown, containing mineral grains and clay, spongy or coarse rugose cast granular structure (5-10 mm in diameter).

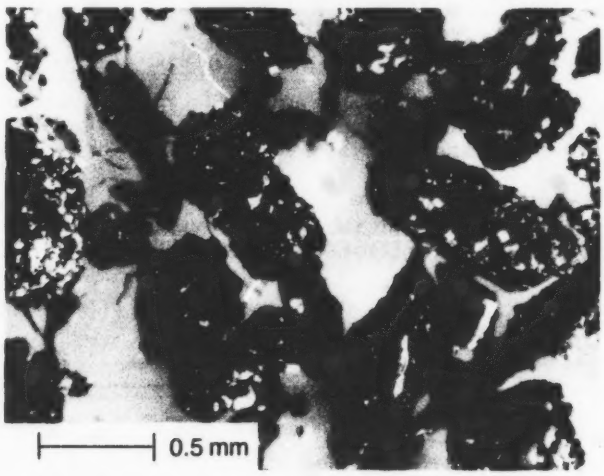

Figure 3. Droppings from the Hda1 horizon of an Orthilepto-moder.

Droppings may be described by their abundance and distribution according to the following classes (Table 17 and Table 18). If possible, an indication of the average size of droppings should be recorded.

TABLE 17. *Droppings - Classes of Abundance*

Class	Description
None	No visible droppings
Few	Droppings occasionally observed but only scattered
Common	Droppings commonly observed
Abundant	Droppings frequently observed in relatively large numbers throughout the horizon

TABLE 18. *Droppings - Classes of Distinction (after Brewer 1964)*

Class	Description
Random	Droppings are distributed randomly, there is no recognizable pattern of distribution
Clustered	Droppings are distributed in clusters or groups
Banded	Droppings are distributed in bands, sheets or layers

Soil Flora

Soil flora includes bacteria, actinomycetes, algae and fungi. In routine studies, the description of the soil flora is narrowed to the fungi that inhabit the humus form profile.

The organisms referred to as fungi form a large and varied group. Rusts, moulds, yeasts and mushrooms are a few of the major kinds of fungi. In most cases, the presence of fungi can be detected by observing a mass of hyphae (thread-like filaments) called a mycelium. A fungal mycelium constitutes the "vegetative" phase of the development of a fungus. While individual hyphae are generally too small to be seen, the mycelial mass is usually visible.

Some mycelia are easily recognized by their colour, while others are transparent. Many are brown, black (dark grey), grey, white, red, yellow or blends of these colours. In acid materials and humid environments, masses of fungal mycelia may form in the Fq horizon, producing a felty feel (tactility).

Fungal mycelia are described by noting their abundance (Table 19), colour and distribution (Table 20). The presence or absence of mycorrhizal root tips is also recorded.

TABLE 19. *Fungal Mycelia - Classes of Abundance*

Class	Description
None	Fungal mycelia not visible
Few	Fungal mycelia occasionally present but only scattered and not easily observed
Common	Fungal mycelia commonly observed
Abundant	Fungal mycelia observed continuously throughout the horizon, often "matting" materials together and creating a "felty" tactility

TABLE 20. *Fungal Mycelia - Classes of Distribution (after Brewer 1964)*

Class	Description
Random	Fungal mycelia are randomly distributed, there is no recognizable pattern of distribution
Clustered	Fungal mycelia are distributed in clusters or groups
Banded	Fungal mycelia are distributed in bands, sheets or layers

Appendix II

Methods of Sampling and Analysis

Sample Collection

As with other soil samples for analysis, the selection of sampling methods for humus form samples depends on the objectives of the study and on the analyses to be undertaken. Details about sampling is given in several authoritative texts (Cline 1944, Peterson and Caloin 1965).

The long-term objective of the proposed humus form classification is to provide characterizations of biological, physical and chemical properties of the recognized taxa. Thus, the humus form population to be sampled should be subdivided (stratified) horizontally into homogeneous sampling units corresponding to taxa. The sampling units are further subdivided vertically according to the recognized horizons constituting the humus form profile. The intensity with which a particular humus form must be sampled to estimate the desired characteristics with given accuracy will depend on the magnitude of the variation within the humus form population under consideration. The purpose of sampling is to estimate these characteristics with an accuracy which will meet the objective at the lowest possible costs.

In the first phase of the ecological classification programme, humus forms are sampled from sample plots subjectively chosen to represent various kinds of ecosystems which are non-randomly distributed on the landscape. Sample plots are approximately 500 m^2 in size. At a representative location within each plot the humus form is sampled along with the rest of the pedon. A result of using this method is that variations within and among sample plots cannot be assessed.

Humus forms may be sampled either by individual horizons or by composite samples of ectorganic and endorganic horizons constituting the humus form profile. Savings can be achieved both in the field and in the laboratory by collecting composite samples, providing that information on individual horizons is not required. The procedure consists of cutting blocks about 10 × 10 cm (plan view) through ectorganic horizons. A similar procedure can be applied to endorganic horizons, or they may be sampled according to standard soil survey practices. Since the ultimate goal is the characterization of the entire humus form rather than its parts, sampling natural cross-sections is, for most of the characteristics, rational and also expedient.

Sample Preparation

The purposes for which the analytical results are to be used, in addition to the natural variation in the samples, will determine how much care will be required in sample preparation and how precise the analytical methods will have to be.

The two primary considerations in preparing humus form samples for analysis are 'drying' and 'grinding'. There are four basic alternatives for drying soil samples, namely: no-drying, air-drying, oven-drying and freeze-drying. The importance of drying arises from the need to minimize any biochemical transformations in the sample which will affect the constituent to be measured. Such transformations are likely to be enhanced by moisture and elevated temperature since these conditions favour microbial and enzymatic activity. The longer these conditions persist, the greater will be the transformations so the longer the period of time between sampling and analysis, the more important it becomes to adopt appropriate sample handling procedures. Some analyses, especially for more labile constituents, require either freeze-drying or analysis of moist samples immediately after sampling. For such constituents, both air-drying and oven-drying are unsatisfactory, as is prolonged storage at ambient temperatures in the moist state. If immediate analysis or freeze-drying are not feasible, storing in a freezer is the next best alternative. While the analyses described in this report do not fall in this category, it is recommended that soil pH should be measured as soon as possible after sampling since a somewhat lower pH is commonly encountered in drier and/or stored samples. It is also advisable to avoid prolonged storage of any moist samples and to avoid subjecting them to elevated temperatures (e.g. by leaving them lying in the sun in plastic bags).

For many common analyses of soil samples (organic or mineral), including those for total elemental content or exchangeable cation content, none of the drying methods is likely to have very significant effects on subsequent analysis. However, some analyses (e.g. extractable sulphate) can be influenced by oven-drying (105°C), so the normal (and most convenient) practice is to air-dry soil samples as soon as possible after sampling. The results of all soil chemical analyses are conventionally reported on an oven-dry (105°C) basis, regardless of the moisture content of the sample used for analysis. Thus, a separate air-dried sample has to be analyzed to determine hygroscopic moisture content.

The heterogeneity of soil materials, especially L and F horizon materials, requires the reduction of particle size to a low enough level to permit representative subsampling for individual analysis so dried samples must be ground. This is particularly important when small subsamples (< lg) are to be used, as is commonly the case with organic samples (e.g. for total C or total N). While various grinding tools can be used (e.g. Wiley mill for highly organic samples), samples should in all cases be ground to pass a 2 mm sieve, and further ground to pass finer sieves (35, 60 or 100 mesh) when smaller subsamples are to be used. Finer grinding and better mixing will improve the precision of subsequent analysis but, at the same time, will increase the time needed for sample preparation. As a general guideline, recommended mesh sizes are given in Table 21.

TABLE 21. *Recommended Mesh Sizes*

Sample size for analysis (g)	Mesh Size
≥ 5	10 (2 mm)
1 - 5	35 (.5 mm)
< 1	60 (.25 mm)

While the principles discussed above apply to all materials, different types of samples may call for different procedures. For example, in preparing foliage samples for analysis, removing moisture and inhibiting enzymatic activity as quickly as possible are overriding considerations. In this case, it is recommended that samples be dried rapidly (at 70°C) in a forced-air oven and that they be kept cold while being transported from the field to the laboratory. However, even these procedures will be unsatisfactory for more labile plant constituents.

Bulk Density[1]

Determining important properties of soil, such as pore space and nutrients on a quantitative basis requires a knowledge of the soil's bulk density and coarse fragment content. Since the methods used for agricultural soils do not work well in forest soils which have abundant coarse fragments, a different method based on a technique suggested by Gardner (1965, p. 95) is used. It consists of two separate steps: in the first, the bulk density of organic materials, mineral materials < 2 mm in diameter, and the coarse fragment volume of all mineral materials ≥ 2 mm and ≤ 4 cm in diameter are determined; in the second, the coarse fragment volume of all mineral materials > 4 cm in diameter is determined. The second step will not be required for those forest soils with no coarse fragments.

Bulk density and coarse fragment volume determinations should be made for each horizon sampled for chemical analysis. However, where several horizons are similar in physical characteristics, one determination of bulk density and coarse fragment volume from a representative horizon (or several horizons if they are thin) will suffice. Specific details concerning sampling will be dealt with in the following sections.

1. Bulk Density and 2 mm to 4 cm Coarse Fragment Volume

In this step 500 to 1000 cm^3 of organic or mineral material should be sampled. A flattened surface 20 cm in diameter is cleared at the top of the desired sample. In the center of this surface a circular hole approximately 10 cm in diameter is cut with a knife, pruning saw or pruning clippers to a depth of approximately 8 cm. Materials from the hole are removed with a small trowel or tablespoon and placed into a plastic sample bag. Some situations that may arise and suggested solutions are as follows:

1. If roots > 1 cm or stones > 4 cm are encountered another attempt should be made nearby to obtain that sample. In some soils or horizons, very high contents of large roots or large coarse fragments will make sampling for this step impractical.
2. When the material to be sampled is under 8 cm in depth, the hole might be widened to attain the desired volume. Large roots, large coarse fragments and horizons that are not flat may prevent widening the hole. The alternative is to take several smaller samples and bulk them together.
3. For sloping horizons the flattened surface will not be level but will conform to the desired sample.

After the sample has been removed, the hole is outlined as closely as possible with thin plastic. Where crevices or pores are evident the outside of the hole may first be lined with stiffer material such as tin or plastic sheeting. Rounded sand or small glass beads are then poured into this hole to the level of the original flattened surface. If sloping horizons were sampled, all but the top part of the surface must be covered with tin or plastic sheeting. Sand or glass beads are poured in through the opening left at the top of the hole. Then, the thin plastic liner and its contents are removed and emptied into a 1000 ml (1 ml = 1 cm^3) graduated cylinder. The volume is recorded both on the data form used for soil profile description and the label for the sample. The plastic bag with the sample and label are carefully sealed (if the bag is < 4 mil in thickness, it is enclosed inside another).

In the laboratory the wet sample is weighed; the weight, minus bag(s) and label, is recorded. The sample is then removed from the plastic bag and placed in a heatproof container (small paper bags are adequate) and dried at 105°C until there is no longer any change in weight. Usually 24 hours is a sufficient period of time. Dry weight is then recorded.

Mineral materials ≥ 2 mm in diameter (coarse fragments) are separated from dried organic material by hand while a 2 mm mesh sieve is used for mineral materials. As much fine material as possible is brushed from the coarse fragments, which are then weighed. Their volume is determined by measuring the amount of water they displace in a graduated cylinder.

The coarse fragment-free bulk density of a sample may be calculated as follows:

$$1) \quad Db = (Md - M \geq 2\ mm) / (Vb - V \geq 2mm)$$

Where:

Db	= bulk density of mineral materials < 2 mm in diameter or of organic materials ($g.cm^{-3}$)
Md	= mass of dry sample (g)
M ≥ 2 mm	= mass of mineral materials ≥ 2 mm (g)
Vb	= volume of hole sampled for bulk density determination (cm^3)
V ≥ 2 mm	= volume of mineral materials ≥ 2 mm (cm^3); use volume of water displaced, or approximate by the following equation: M ≥ 2 mm / 2.65 ($g.cm^{-3}$)

Gravimetric moisture content on a dry-mass basis (θ dw) may be calculated as follows:

$$2) \quad \theta\ dw = (Mw - Md) / Md = (Mw / Md) - 1$$

Where:

Mw	= mass of wet sample (g)
Md	= mass of dry sample (g)

[1]This section was prepared by F.C. Nuszdorfer, Ministry of Forests.

Gravimetric moisture content on a coarse fragment-free basis (θ) may also be calculated as follows:

3) $\theta = ((Mw - M \geq 2\ mm) / (Md - M \geq 2\ mm)) - 1$

Where:

Mw	= mass of wet sample (g)
M ≥ 2 mm	= mass of mineral materials ≥ 2 mm (g)
Md	= mass of dry sample (g)

For comparisons of moisture content between locations, the figure for the coarse fragment-free basis (3 above) is more meaningful than that based on dry mass (2 above).

Water content on a bulk volume basis (θ vb) may be calculated as follows:

4) $\theta vb = (Mw - Md) / Vb\ (1.0)$

Where:

Mw	= mass of wet sample (g)
Md	= mass of dry sample (g)
Vb	= volume of hole sampled for bulk density determination (cm^3)
1.0	= approximate density of water ($g.cm^{-3}$)

This permits calculation of volume of water available for plant growth if the zone of supply is defined.

2. Coarse Fragments > 4 cm

As a soil pit is excavated, rocks > 4 cm in diameter should be removed from the soil and separated by horizon into gravel (< 7.5 cm), cobble (7.5 - 25 cm) and stone (>25 cm) components. When horizons are thin or indiscernible, the separation may be by depth increments. After a decision has been made regarding the number and location of samples to be taken for step 1 (above), the coarse fragments >4 cm may be combined together to correspond to these samples. The mass of all components is determined with spring scales which have been calibrated for accuracy. Occasionally, cobbles and stones may occupy a volume corresponding to more than a single sample from step 1. When this is the case, an estimate of the proportions in the respective layers will have to be made.

Measurement of the dimensions of the soil excavation from which the coarse fragments were taken permits the volume to be calculated. This is facilitated if the shape of the excavation approximates a square or rectangular box.

Where there is a high content of evenly distributed gravel >4 cm and cobbles, it will be sufficient to sample only a portion of the total volume of the soil pit. A section of predetermined thickness could be sliced from a face of an established soil pit and used to determine gravel and cobble content. The entire pit must be used to determine stones content.

Gravel content on a volume basis (CFvolg) is calculated as follows:

5) $CFvolg = (V \geq 2\ mm / Vb) + (Mg > 4\ cm / Vpg\ (2.65))$

Where:

V ≥ 2 mm	= volume of mineral materials ≥ 2 mm and ≤ 4 cm in diameter as determined in step 1 (cm^3)
Vb	= volume of hole sampled in step 1 (cm^3)
Mg >4 cm	= mass of gravel >4 cm (g)
Vpg	= bulk volume of soil from which the gravel >4 cm was taken (cm^3)
2.65	= approximate particle density of mineral materials ($g.cm^{-3}$)

Cobble content on a volume basis (CFvolc) is calculated as follows:

6) $CFvolc = Mc / Vpc\ (2.65)$

Where:

Mc	= mass of cobbles (g)
Vpc	= bulk volume of soil from which the cobbles were taken (cm^3)
2.65	= approximate particle density of mineral materials ($g.cm^{-3}$)

Stone content on a volume basis (CFvols) is calculated as follows:

7) $CFvols = Ms / Vps\ (2.65)$

Where symbols are as for equations 5, and

Ms	= mass of stones (g)
Vps	= bulk volume of soil from which the stones were taken (cm^3)
2.65	= approximate particle density of mineral materials ($g.cm^{-3}$)

The total coarse fragment content on a volume basis (CFvol) is obtained by summing the results from equations 5, 6, and 7:

$$CFvol = CFvolg + CFvolc + CFvols$$

or, if the bulk volumes of soil from which the gravel >4 cm, cobbles, and stones were taken were equal, i.e. Vpg = Vpc = Vps, then, given Vpt = Vpg = Vpc = Vps:

8) $CFvol = (V \geq 2\ mm / Vb) + ((Mg > 4\ cm + Mc + Ms) / Vpt\ (2.65))$

Where:

V ≥ 2 mm	= volume of mineral materials ≥ 2 mm and ≤ 4 cm in diameter (cm^3)
Vb	= volume of hole sampled in step 1 (cm^3)
Mg > 4 cm	= mass of gravel > 4 cm (g)
Mc	= mass of cobbles (g)
Ms	= mass of stones (g)
2.65	= approximate particle density of mineral materials ($g.cm^{-3}$)

Total porosity in organic materials (Sto) is the percentage of total volume not occupied by solids:

9) $Sto = 100(1 - CFvol)((1 - (Db / 1.5))$

Where:

CFvol = coarse fragment content on a volume basis

Db = bulk density (in this case, of organic materials) ($g.cm^{-3}$)

1.5 = approximate particle density of organic materials ($g.cm^{-3}$)

Total porosity in mineral materials (Stm) is calculated as follows:

10) $Stm = 100\,(1 - CFvol)\,((1 - (Db / 2.65))$

Where symbols are as for equation 9 (above) and:

Db = bulk density (in this case, of mineral materials < 2 mm in diameter) ($g.cm^{-3}$)

2.65 = approximate particle density of mineral materials ($g.cm^{-3}$)

The quantity of nutrients available for plant growth is indexed as follows:

11) $kg\ X/ha = (1 - CFvol)\,(\%X < 2\ mm / 100)\,k\,(Db)\,Vs$

Where:

kg X/ha = index of quantity of a nutrient × per hectare

CFvol = coarse fragment content on a volume basis

%X < 2 mm = the percentage of the available nutrient on a dry mass basis in the organic matter or in the mineral materials < 2 mm in diameter

k = conversion factor ($1kg\ .\ 10^{-3}g^{-1}$)

Db = bulk density of mineral materials < 2 mm in diameter or of organic materials ($g.cm^{-3}$)

Vs = volume of soil in 1 ha; this volume may be calculated as follows:
(soil thickness in cm) ($10^8\ cm^2.ha^{-1}$)

Recommended Chemical Analysis

In humus form studies, three types of analysis are potentially of value, namely:

1. Analysis of organic samples for diagnostic purposes, in order to identify the humus form;
2. Analysis of organic and mineral horizon samples for parameters that may elucidate the relationships between humus composition and the associated environment, or
3. Analysis which permit interpretation of the humus form in terms of management decisions.

In the present state of knowledge, it is by no means clear to which category some common analyses belong. Nor is it certain which of many possible analyses will prove most valuable for diagnostic or interpretive purposes. Accordingly, the authors consider it important to continue to collect information on a number of parameters that can not as yet be interpreted with any confidence.

The methods recommended below are based on the current understanding of relationships between properties of humus form horizons, and both productivity and humus form taxa. In particular, recent studies in the Coastal Western Hemlock Biogeoclimatic Zone of British Columbia have generated a number of useful hypotheses with regard to these relationships (Lowe and Klinka 1981). The specific methods outlined were selected either on the basis of common use in routine soil characterization, or demonstrated significance in differentiating between humus forms (in the CWH Zone), in combination with relative speed and simplicity of laboratory procedures.

For discrimination purposes, the following analyses on humus form[1] samples are presently considered the most promising:

1. Organic fraction analysis.

a. lipid fraction
b. carbon and bound sugars in soluble polysaccharide fraction
c. carbon and nitrogen in humic acid extract
d. carbon and polyphenol carbon in fulvic acid extract
e. optical properties of humic acid

2. Routine analysis.

f. cation exchange capacity and exchangeable base cations (Ca, Mg, K, Na)
g. pH
h. total C, total N, and mineralizable N
i. total Fe, Al and Mg

In broader studies focussing on the genesis of humus forms or on humus form relationships to productivity, the following analyses are proposed in addition to those listed above:

j. for organic samples - total elemental analysis for Ca, Na, K, Mn, and P.
k. for mineral samples - pyrophosphate-extractable Fe and Al.

1. Organic Fraction Analysis

Separation of organic fractions is based on the first three steps of a more complex fractionation scheme (Lowe 1974), involving successive extractions with ethanol:benzene (1:1), 0.1 N H_2SO_4 and 0.1 N NaOH, all at room temperature (Figure 3).

Four primary fractions are obtained, namely:

a. Fraction A (lipids)
b. Fraction B (soluble polysaccharides)
c. Fraction H1 (humic acid)
d. Fraction F1 (fulvic acid)

Fraction A is determined gravimetrically and the remaining fractions by wet oxidation with $K_2Cr_2O_7$ in terms of their carbon contents. Bound sugar content of

[1] A humus form sample may include a sample of endorganic horizons which should be treated as a different entity in collection and analysis.

fraction B is determined by the phenol-sulphuric acid procedure (Whistler and Wolfram 1962), following hydrolysis with 1N H_2SO_4. Nitrogen contents of fractions H1 and F1 are determined by semimicrokjedahl, and designated NH1 and NF1. The fulvic acid fraction is further fractionated on polyvinylpyrrolidone to separate the polyphenolic moiety (termed fraction FA) of this fraction (Lowe 1975).

Details of the recommended analysis concerning organic fraction analyses are given by Lowe (1974) and Lowe and Klinka (1981). It should, however, be emphasized that as more information becomes available, substantial revisions in these recommendations may become necessary.

2. Routine Analysis

Reaction (pH): Determined electrometrically in 1:8 suspensions in distilled water and in 0.01M $CaCl_2$ (Peech 1965) for organic samples. For mineral horizon samples, a soil: solution ratio of 1:2 (mass:volume) us suggested, although 1:1 is more commonly used for pH determination in water.

Total carbon (C%): By induction furnace and carbon analyser (Leco and other equivalent equipment). It should be noted that some interpretation problems exist for samples containing charcoal or free $CaCO_3$.

Total nitrogen (N%): By semi-microkjeldahl (Bremner 1965) digestion and NH_4-N determination by colorimetric or steam distillation methods (see CEC below). The C/N ratio is calculated from C and N values.

Mineralizable nitrogen: Is determined by the anaerobic incubation method of Waring and Bremner (1964). Released ammonium is determined colorimetrically using the same methods as described for total nitrogen.

Cation exchange capacity (CEC meq/100 gm): The neutral 1N ammonium acetate procedure (NH_4OAc, pH 7.0) (Chapman 1965) using steam distillation-titration (kjeldahl) or the colorimetric phenol hypochlorite reaction (autoanalyser or manual) for determination of NH_4-N displaced.

There is some doubt as to whether this widely used procedure is the best for organic samples. Certainly it cannot be expected to give a reliable estimate of CEC under field conditions in strongly acidic soils, due to the pH-dependence of charge on organic colloids. Alternative approaches using unbuffered salts or 'summation of cations' are discussed by Chapman (1965). More work is needed on this problem.

Exchangeable base cations (ExCa, ExMg, ExK, ExNa meq/100 gm): Displacement with neutral 1N ammonium acetate (first stage of CEC analyses above) and cation determination by atomic absorption analysis. Care must be taken to circumvent the common problems of matrix and interference effects and reagent blanks. Nitrous exode flame is preferable for Ca and Mg.

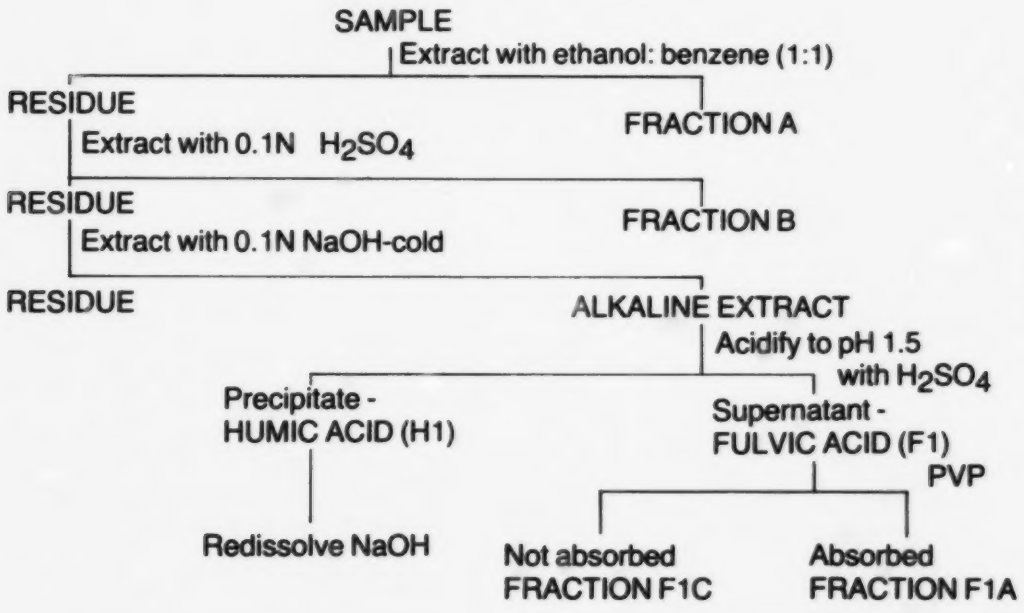

Figure 3. Separation of organic fractions from humus form samples.

Pyrophosphate-extractable Fe and Al: Extraction of Fe and Al with sodium pyrophosphate at pH10 and 25°C, following the procedure of Bascomb (1968). Fe and Al are determined by atomic absorption spectroscopy.

Extractable phosphorus: In mineral horizon samples is determined by the Bray method of acid ammonium fluoride extraction as described by Olsen and Dean (1965) followed by colorimetric determination of the P using the molybdenum blue method.

Extractable sulphate-sulphur: In mineral horizon samples is determined by ammonium acetate extraction (Bardsley and Lancaster 1965). Extracted sulphate is reduced to sulphide by HI and sulphide is then determined colorimetrically (Kowalenko and Lowe 1972).

Total Ca, Mg, K, Fe, Al, Na, Mn and P are determined following wet oxidation with Caro's acid (H_2SO_4 + H_2O_2). using a modification of the method of Parkinson and Allen (1975). P in the digest is determined colorimetrically with the metavanadate procedure, and Ca, Mg, K, Fe, Al, Na and Mn by atomic absorption analysis. Nitrogen can also be determined on these digits.

A summary of recommended chemical analyses for humus form studies is given in Table 22. Determination of the measurements recommended below will also allow calculation of the additional derived variables: ExCa/ExMg, ExCa/ExK, and others.

TABLE 22. *Recommended Chemical Analysis*

Recommended analysis
pH ($CaCl_2$)[1]
Total C[1]
Total and mineralizable N[1]
Cation exchange capacity and exchangeable cations[1]
Lipid fraction[2, 3]
Carbon and bound sugars in fraction B[2, 3]
Carbon and nitrogen in humic acid extract[2, 3]
Carbon and polyphenol carbon in fulvic acid extract[2, 3]
Optical properties (E4 and E4/E6) of humic acid extract[2, 3]
Total Ca, Mg, K, Na, Fe, Al, Mn and P[2]
Pyrophosphate-extractable Fe and Al[4]
Extractable-P[4]
Extractable-S[4]

[1]All samples
[2]Samples of ectorganic horizons
[3]Samples of endorganic horizons
[4]Samples of A & B mineral horizons

Appendix III
Sample of the Form Used In Humus Form Description

HUMUS FORM PROFILE DESCRIPTION

B.C. Ministry of Forests 1990

Project I.D.

Surveyor

Plot No.

Page ___ of ___

Horizon Designation	Lab No	Depth	Thickness Min | Max	Boundary Dist | Form	Moisture Status	Colour Aspect	Colour Mun Not	Structure	Consistence	Character	Texture	Roots Ab	Roots Size	Roots Qr	Roots Distr

Horizon Designation	Non-conforming Materials Kind	Non-conforming Materials Distr	Non-conforming Materials Size	Non-conforming Materials Ab	Soil Biota Flora	Soil Biota Fauna	Origin of Material	Reaction (pH)	Bulk Density	Notes	Cross-section Drawing

Humus Form Taxon

© [illegible] LTD. MADE IN [illegible] CANADA [illegible]

POOR

QUALITY

ORIGINAL